DEVELOPMENT OF MONITORING PROTOCOLS FOR THE NORTHERN COLORADO PLATEAU PROTOTYPE CLUSTER: ANNUAL REPORT FY03 AND REQUEST FOR FUNDING FY04

October 30, 2003

USGS Contacts:

Dr. Jayne Belnap
USGS-BRD
Canyonlands Field Station
2290 S. West Resource Blvd.
Moab, UT 84532
Telephone: 435.719.2333
Email: Jayne_Belnap@usgs.gov

Dr. Mark Miller
USGS-BRD
Canyonlands Field Station
2290 S. West Resource Blvd.
Moab, UT 84532
Telephone: 435.719.2340
Email: Mark_Miller@usgs.gov

NPS Contact:

Dr. Thom O'Dell
National Park Service
Northern Colorado Plateau Prototype
2282 S. West Resource Blvd.
Moab, UT 84532
Telephone: 435.719.2358
Email: Thomas_E_O'Dell@nps.gov

TABLE OF CONTENTS

I. INTRODUCTION

The U.S. Geological Survey Biological Resources Division (USGS-BRD), Canyonlands Field Station, is a partner in the development of monitoring protocols for five National Park Service (NPS) units of the Northern Colorado Plateau (NCP) Prototype Cluster[1]. The NCP Prototype Cluster has been identified by NPS and USGS as the monitoring prototype for the arid lands biome (http://science.nature.nps.gov/im/monitor/vsmAdmin.htm#Prototypes), thus NCP protocols are expected to be generally applicable (perhaps with modification) to monitoring conducted in other arid-land NPS units. Because the five NCP prototype parks are integrated in the 16-park Northern Colorado Plateau Network (NCPN), the prototype and network programs are closely linked and USGS-BRD protocol-development work is in-part driven by the combined monitoring needs of the entire NCPN. The 19-unit Southern Colorado Plateau Network (SCPN) also is working closely with the NCPN and NCP Prototype Cluster during the planning and design phases of network vital-signs monitoring. In 2003 the SCPN, NCPN, and USGS-BRD Canyonlands Field Station agreed to work together in the coordinated development of protocols for long-term ecological monitoring.

Objectives

Following are general objectives for USGS-BRD protocol-development work:

- Develop (or acquire) protocols required for vital-signs monitoring in parks of the NCP Prototype Cluster, considering (where possible) monitoring needs of the NCPN, the SCPN, and other arid-land NPS units.
- Test monitoring protocols as needed through pilot-implementation studies.
- Conduct research to verify linkages between monitoring indicators (vital signs) and ecological processes and attributes.
- Conduct research to evaluate indicator variability and responsiveness of indicators (and associated ecological attributes) to management.
- Conduct research to assist in the determination of management thresholds for monitoring indicators.
- Periodically review and revise protocols for prototype parks after they have become operational.

NCPN Vital Signs and USGS Protocol-Development Activities

In September 2003, vital signs were selected by 16 parks of the NCPN (Miller et al. 2003). Table 1 lists high-priority NCPN vital signs and identifies those that are addressed by on-going USGS-BRD protocol-development activities.

---

[1] Prototype parks include Canyonlands National Park (CANY), Arches National Park (ARCH), Capitol Reef National Park (CARE), Dinosaur National Monument (DINO), and Natural Bridges National Monument (NABR).

Table 1. High-priority vital signs selected by parks of the Northern Colorado Plateau Prototype Cluster and Northern Colorado Plateau Network. Vital signs in **bold print** are addressed by on-going USGS-BRD protocol-development work. Note that there is considerable overlap among vital-sign categories.

VITAL-SIGN CATEGORY		HIGH-PRIORITY VITAL SIGNS
Climatic conditions		**Precipitation, temperature, and wind patterns**
Air quality		Atmospheric deposition, visibility, and tropospheric ozone levels
Soil, water, and nutrient dynamics		**Upland soil / site stability, upland hydrologic function, and nutrient cycling**
		Stream flow regime, stream / wetland hydrologic function, and groundwater dynamics
Water quality		Dissolved oxygen, pH, conductivity, water temperature, and flow / stage
Disturbance regimes		Fire regimes and **extreme climatic events**
Biotic integrity	***Predominant* plant communities**	**Predominant upland plant communities**
	***At-risk* species or communities**	Threatened, endangered, or sensitive vertebrate populations (including **amphibians**) and **plant populations**
		Riparian-obligate bird communities
		Native grasslands, sagebrush shrublands, and riparian / wetland plant communities
	***Focal* species or communities** (key contributors to biodiversity and/or ecosystem function)	**Riparian / wetland communities**, including springs, seeps, and hanging gardens
		Biological soil crusts and aquatic macroinvertebrates
	***Endemic* species or *unique* communities**	Hanging-garden communities
		Rare / endemic plant populations
Landscape-level patterns		**Land cover, land use, park insularization, landscape fragmentation and connectivity**
Stressors		Park use by visitors, **invasive exotic plants**, and adjacent / upstream land-use activities

II. REPORT FOR FY2003

This section reports on protocol-development activities conducted with FY2003 funding. Because funding was received late in the fiscal year (April), some funded activities have not yet been initiated.

Climatic Conditions

We investigated modeling approaches for improved climate monitoring and decided that the network needed models that would estimate spatial and temporal variations in water and energy balances across the landscapes of NCP parks. These models would then enable us to stratify the landscape for monitoring design purposes, predict ecosystem sensitivity to drought conditions, predict variations in soil resistance and resilience to disturbance as a function of moisture availability, and assist us in interpreting temporal and spatial patterns of change in park resources. We issued a contract for this work to USGS-WRD in March 2003. The following products are associated with this project:

i. Digital spatial coverages gridded at 30-m spatial resolution for all NCPN park units and 270-m spatial resolution for state of Utah, as follows:
   - Monthly mean precipitation
   - Monthly mean potential evapotranspiration
   - Monthly mean snow accumulation
   - Monthly mean snowmelt
   - Monthly mean aridity index

   All monthly coverages have been developed to allow aggregation to user-specified seasonal periods (e.g., Figure 1).

ii. FGDC-compliant metadata associated with each of the digital coverages (to be delivered by 31 Dec. 2003).

iii. Written report (or publication) describing origin / lineage of digital coverages (including modeling methods), underlying assumptions of modeling techniques, and brief description of how coverages should and should not be interpreted and applied (to be delivered by 31 Dec. 2003).

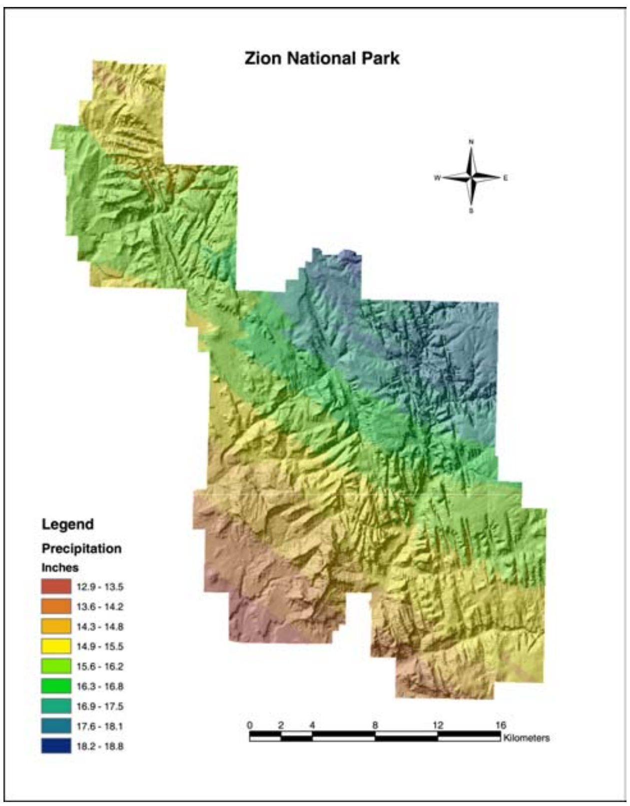

Figure 1. Topographically modeled mean annual precipitation for Zion National Park, Utah.

Upland Ecosystems – Ground-Based Measures of Hydrologic Function, Soil / Site Stability, & Nutrient Cycling

Primary ecosystem processes that must be functional to ensure the sustainability of terrestrial ecosystems are (a) the capture and retention of water (hydrologic function), (b) the capture and retention of nutrients (nutrient cycling), and (c) the capture and retention of photosynthetic energy in organic materials. Degraded ecosystems are characterized by accelerated rates of water, nutrient, and organic-matter losses compared with similar ecosystems relatively unaffected by human activities. These concepts are incorporated in NCPN three vital signs addressed by protocol-development work:

- *Upland hydrologic function* – capacity of a site to capture, store, and safely release water from rainfall, run-on, and snowmelt, to resist a reduction in this capacity, and to recover this capacity following degradation (Pellant et al. 2000).
- *Upland soil / site stability* – the capacity of a site to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water (Pellant et al. 2000).
- *Nutrient cycling* – the capacity of a site to capture, retain, and cycle mineral nutrients.

Soil and *biological soil crusts* are disproportionate contributors to the functional status of these three vital signs. Soil is a fundamental resource because it functions as a medium for water capture and retention, nutrient cycling and retention, and primary production. Soil properties that *affect* functioning of primary ecosystem processes and are *effected by* management activities (hence subject to monitoring for change detection) include stability (susceptibility to erosion by wind and water), structure, organic-matter content and fertility, biotic activity, surface roughness, and surface crusting (biotic or physicochemical). Because of their capacity for change in relation to management, these are referred to as *dynamic soil properties*. In most arid-semiarid ecosystems, especially those of the Colorado Plateau, biological soil crusts (composed primarily of cyanobacteria, mosses, and lichens) are an integral part of, and thus influence, all the soil properties listed above. They are critical in the stabilization of soils, in providing organic matter and soil structure, in adding and maintaining soil fertility and in influencing local hydrologic cycles. In addition, they are highly responsive to management actions. For these reasons, much of the protocol development activities for soil, water, nutrient dynamics have been focused on biological soil crusts.

There were two main challenges inherent in developing biological soil crusts as vital signs or measures of vital signs. The first was to develop methods for measuring soil crusts in easy, non-technical, repeatable, and non-destructive ways. The second was determining what crust development stage should trigger management action for a particular vital sign, and tying this, using solid solid science, to ecosystem function in a highly defensible manner.

Much research has been done on the ecosystem roles played by biological soil crusts on the Colorado Plateau and other western U.S. desert regions. These studies have demonstrated that the presence of well-developed lichen-moss soil crusts preclude soil loss by wind (Figures 2 and 3) and water (Barger 2003) and enhances the nutrient status of soils (Evans and Ehleringer 1993). The presence of these well-developed soil crusts also increases local water infiltration (Barger 2003). In addition, well-developed crusts are destroyed by trampling or vehicle traffic. Therefore, their presence indicates that soil aggregate structure, compaction levels, soil food webs and associated nutrient cycles are healthy and functioning at a high level. Most of the above studies compared well-developed soil crusts to adjacent, recently disturbed areas with no or very low crust cover, where wind and water erosion readily removed soils, soils were compacted, structure destroyed, and soil nutrients were lower as a result of the disturbance. However, there had been no work on understanding what level of soil crust development was necessary to maintain soil stability, structure and fertility at a minimum sustainable level and/or acceptable to land managers. To address these two issues, we have done the following:

A. *Measuring Soil Crust Development*: Assessment of the developmental stage of biological soil crusts has traditionally been done estimating total crust cover, cover by species, and/or estimating biomass of cyanobacteria using chlorophyll a or nitrogen-fixation potential. However, the first method requires hard-to-find technical expertise and the find a more simple approach. Using volunteers consisting of non-biologists second is both destructive and requires sophisticated equipment. Therefore, we set out to find a more simple approach. Using volunteers consisting of non-biologists (administrative staff, park rangers, etc.) and biologists, we tested a variety of methods for ascertaining crust development stage that was non-destructive and non-technical, but repeatable using untrained personnel. We found that people were consistently able to tell about different levels of soil darkness when given a set of photos to compare to the samples (Figure 4).

B. *Soil Darkness, Soil Stability, and Ecosystem Function*: We then analyzed samples of different darkness levels and found a consistent correlation between sample darkness and cyanobacterial biomass as estimated by chlorophyll *a* (Figure 5), soil aggregate stability as estimated by the slake test (Figure 6), and soil stability as estimated by polysaccharide concentrations in the soil (Figure 7). These results are very exciting, as previous studies in this and other desert ecosystems have shown a positive correlation between cyanobacteria biomass and resistance to wind erosion (Belnap and Gillette 1997, 1998; McKenna-Neuman and Maxwell 1996; Belnap et al. 2003) and between soil aggregate stability as estimated by the slake test and resistance to water erosion (Herrick et al. 2001, Barger 2003). Because polysaccharides are the materials that bind soil particles together, their concentrations should also indicate resistance to water and wind erosion, although this connection had not yet been studied.

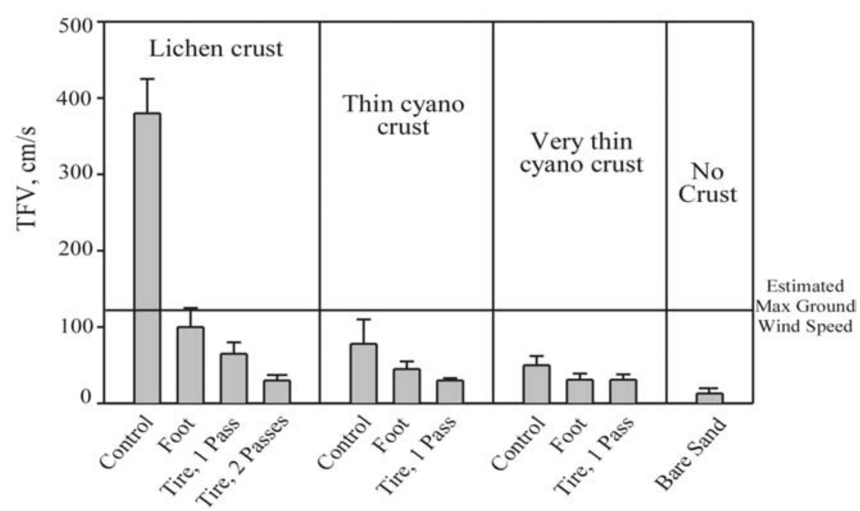

Figure 2. Threshold friction velocities (the wind speed that moves soil particles) for sandy soils with different levels of biological crust cover near Moab, UT. Note that soils with well-developed lichen crusts are much more stable than soils with a thin or very thin cyanobacterial crust, or no crust cover. This shows that soils that lack lichen soil crusts are vulnerable to wind erosion.

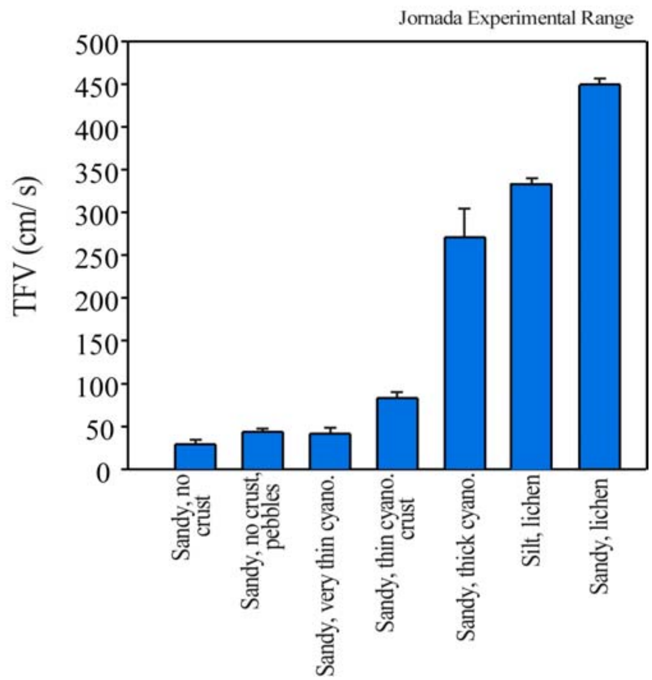

Figure 3. Threshold friction velocities for different soils (sandy, silty) with different biological soil crust covers near Las Cruces, NM. Note that soils without thick cyanobacterial or lichen crusts are vulnerable to wind erosion.

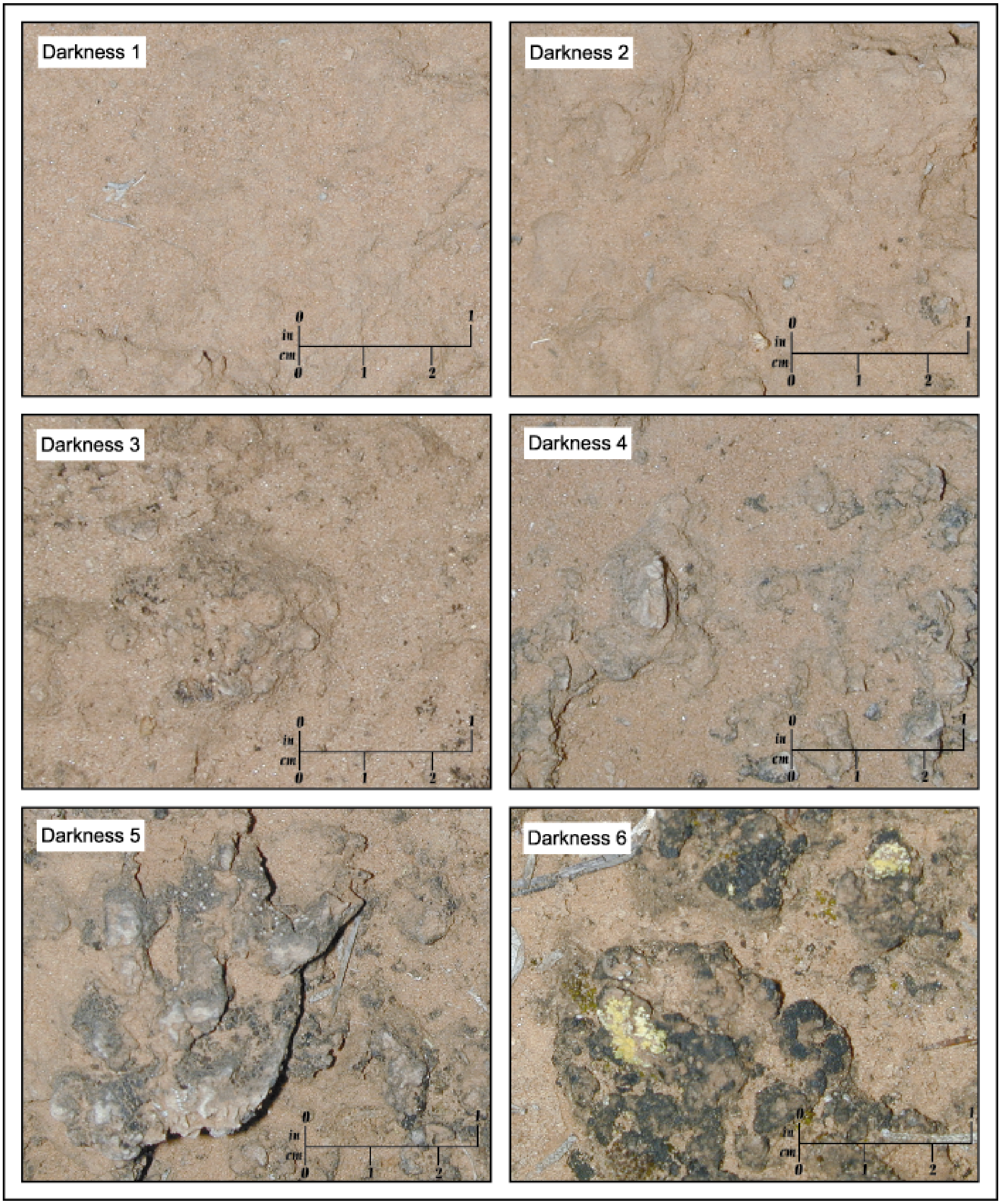

Figure 4. Visual categories of crust darkness used in crust condition assessment.

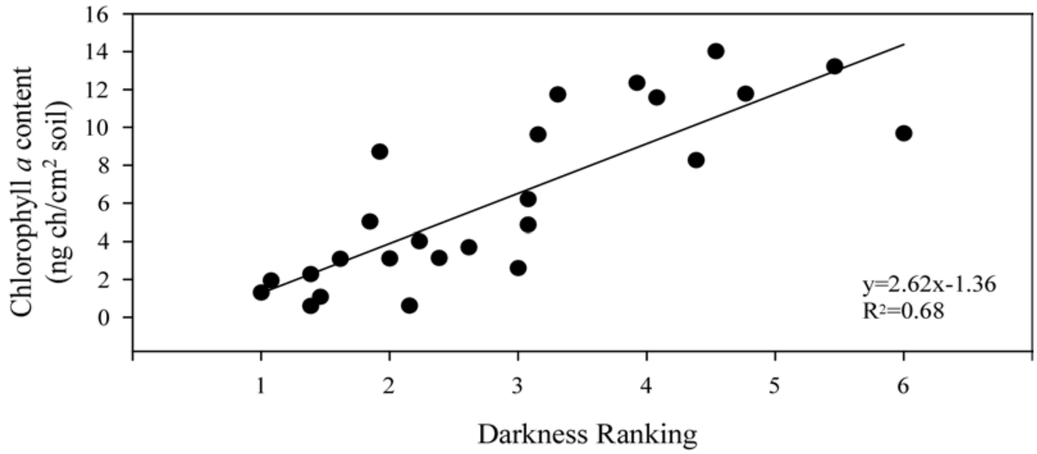

Figure 5. The relationship between chlorophyll a content and the visual categories of biological soil crust darkness.

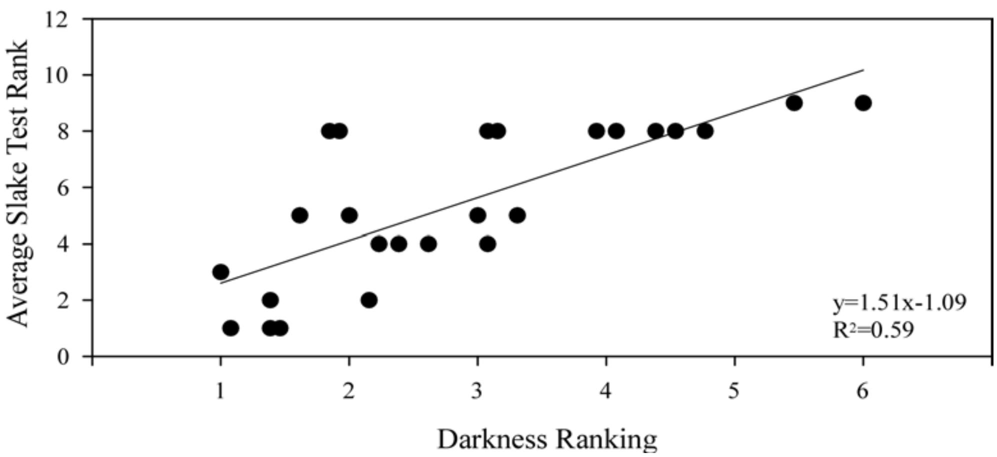

Figure 6. The relationship between the slake test (see text) and the visual categories of biological soil crust darkness.

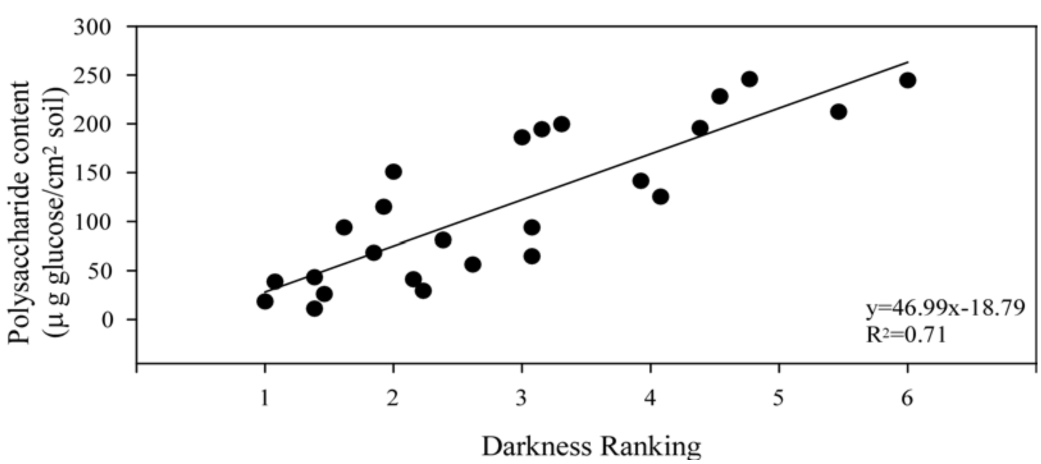

Figure 7. The relationship between polysaccharide content and the visual categories of biological soil crust darkness.

C. *Wind Erosion*: We then tested the relationship between the soil darkness index and the resistance of soil to wind erosion using a wind tunnel on both sandy (Figure 8) and silty loam (Figure 9) soils. These results indicate that there are 3 thresholds apparent in wind resistance of soils covered by soil crusts. Whereas soils in crust categories 1 and 2 are easily erodible at most wind speeds, and those in crust categories 5 and 6 are not erodible even under high wind speeds, those in categories 3 and 4 are susceptible to erosion during moderately high to high wind speeds. Sandy and silty loam soils were very similar. Therefore, it is suggested that soil crusts with a development level of 4 or less be considered a management for risk to wind erosion. During a separate study in the Mojave Desert, we also found a correlation between wind erodibility and chlorophyll content (Figure 10). Because chlorophyll content is highly correlated with our darkness index, we believe this approach will also work in the Colorado Plateau region.

D. *Water Erosion*: We have begun similar tests with a rainfall simulator. We have started testing soils in category 1 and 2 and those in category 5 and 6. Preliminary data indicate that, similar to wind erosion, category 1 and 2 soils are easily eroded and category 5 and 6 soils are almost impossible to erode. We will be testing category 3 and 4 soils this fall to determine appropriate management trigger thresholds.

E. *Water Infiltration/Hydrologic Function*: To establish appropriate management thresholds for water infiltration and hydrologic function, we have begun developing and testing a visual categorization of crusts combining darkness and surface roughness. Once we establish categories that are reliably separated by people of varying technical skill, we will use the rainfall simulator to identify management trigger thresholds.

F. *Silt Fences*: We have tested the efficacy of using silt fences to measure sediment production via water erosion from slopes. They have worked wonderfully, being simple, cheap, reliable and easy to use. We are currently installing silt fences under slopes dominated by crusts in categories 1-2, 3-4, and 5-6. This will enable us to field test the rainfall simulator results (section D, above).

G. *Nutrient Cycling and Soil Food Webs*: We have tested nitrogen fixation in soils covered by crust categories 1-2 and categories 5-6, and have found fixation rates are much higher in the latter category. We have also measured soil food web components (nematodes, protists, bacteria, and fungi) under categories 1-2 and 5-6, and found that the darker crusts have more diversity and greater abundance of species than the lighter categories. This implies that decomposition is faster, and therefore nutrients ,pre availabile to plants, in the darker crusts than the lighter crusts. In FY04, we will test crust categories 3-4 to determine management trigger thresholds for both nitrogen fixation and soil food web composition.

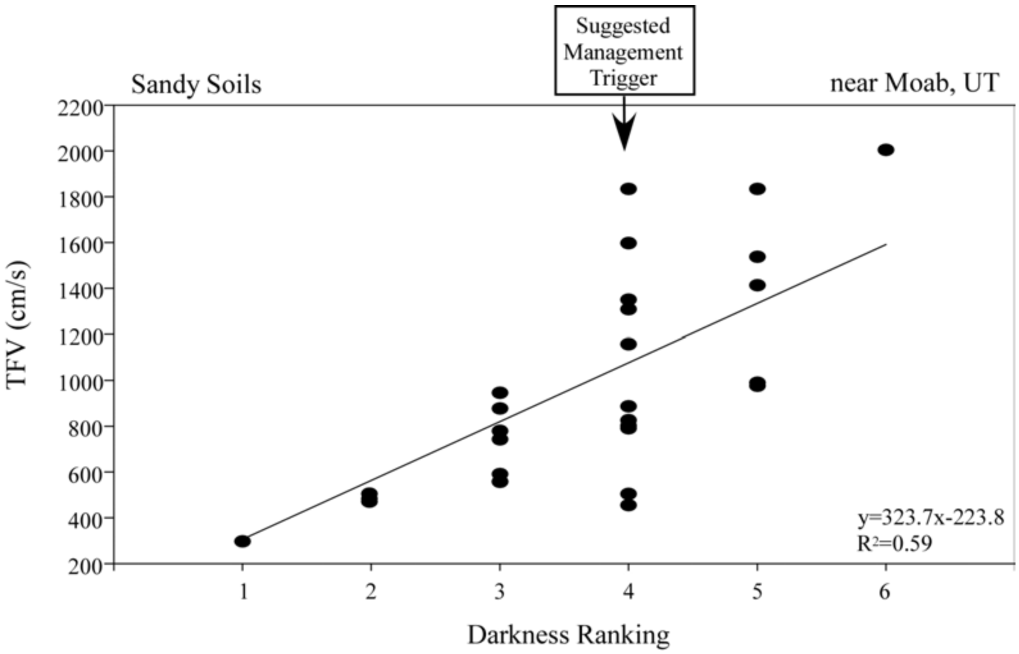

Figure 8. The relationship between the darkness of biological soil crusts on sandy soils and wind erodibility, as indicated by threshold friction velocities. Because visual class 4 has TFV values that are vulnerable to wind erosion, crust in or below this class (1-4) should trigger management action.

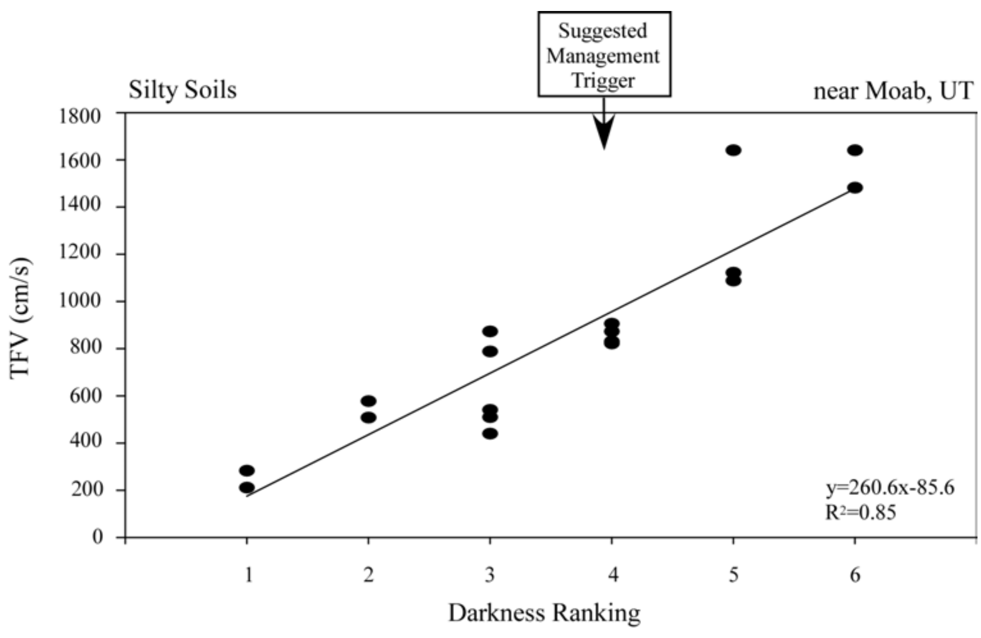

Figure 9. The relationship between the darkness of biological soil crusts on silty soils and wind erodibility, as indicated by threshold friction velocities. Because visual class 4 has TFV values that are vulnerable to wind erosion, crust in or below this class (1-4) should trigger management action.

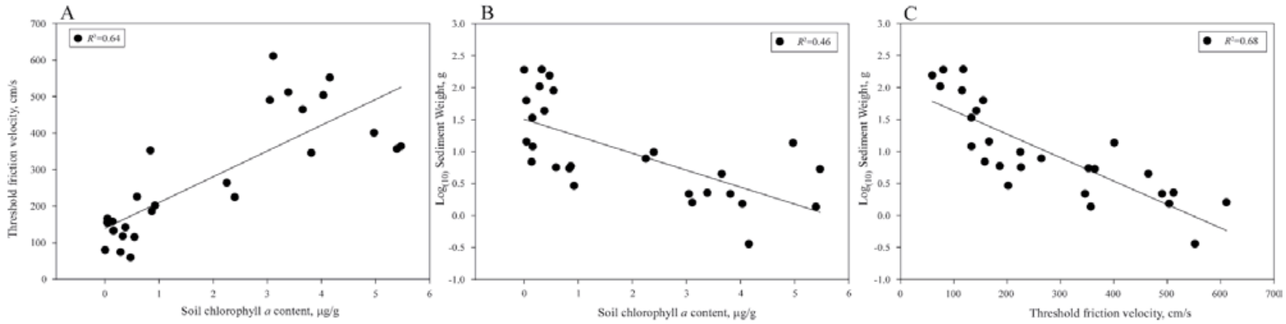

Figure 10. Chlorophyll content of biological soil crusts in Mojave Desert soils is also correlated with both the level of wind it takes to erode soil (TFV) and the amount of soil moved by the wind on undisturbed soils. Therefore, soil darkness indices are expected to work in this regard as well.

Riparian Ecosystems – Flow Regime, Hydrologic Function & Vegetation Composition / Structure

Objectives of the riparian vegetation assessment and monitoring supported with FY2003 funding include development of a monitoring protocol, in conjunction with a pilot field study to refine and implement the protocol. Mike Scott, riparian ecologist with USGS-BRD in Fort Collins, will lead this work. Our approach will include a review of existing assessment and monitoring approaches, from which we will develop a draft monitoring protocol. The draft protocol will involve intensive, site-based monitoring as well as more spatially extensive monitoring using remotely sensed data, and will be based on the premise that riparian vegetation communities are structured by the dominant fluvial geomorphic processes acting along a stream. Following development of the draft protocol, we will select 3-4 candidate field sites where we will implementation the protocol, assess its effectiveness and practicality, and make appropriate refinements. Literature review, resulting in a written report describing development of the draft protocol will take place during winter of 2003-2004. Candidate field sites, including large rivers and small ephemeral drainages, will be selected in parks of the Northern Colorado Plateau Network in spring of 2004. Field implementation and refinement of the monitoring protocol will take place during the spring and summer of 2004, resulting in a final draft riparian vegetation monitoring protocol designed to track the structure and function of riparian and riverine wetland plant communities over time and on a spatial scale relevant to park management activities.

Application of Remote-Sensing Technologies to Long-Term Ecological Monitoring

FY2003 funding will be used to investigate applications of remote-sensing technologies to long-term ecological monitoring. Due to the large size of most NCP prototype parks and the need to monitor beyond as well as within park boundaries, remote-sensing technologies (defined as any type of aerial sensing) will likely play a role in an integrated, multi-scale monitoring program. Ray Kokaly (USGS-GD, Denver) has been identified as a partner in the assessment of possible approaches to vital-signs monitoring via remote-sensing techniques. With FY2003 funding, he will evaluate the utility and cost-effectiveness of these broad-scale remote-sensing technologies for addressing monitoring needs of NCP prototype parks and NCPN parks. Selected broad-scale imagery (e.g., LANDSAT) also will be acquired for pilot testing. These images will be analyzed to assess their utility for change detection in Colorado Plateau landscapes. The product of this work will be a report which summarizes the results of these evaluations and makes recommendations concerning feasible, cost-effective strategies for spatially extensive monitoring with remote-sensing technologies.

Many resource-management issues faced by parks are associated with networks of interconnected corridors (e.g., roads, trails, riparian zones) and nodes (e.g., trailheads, roadside pullouts, campgrounds). These corridors and nodes are areas where the probabilities of rapid environmental changes are much greater than in the surrounding landscape matrix due to concentrated visitor-use patterns, dynamic natural disturbance regimes, or both (riparian corridors). In many cases, ground-based approaches will be inadequate for monitoring conditions in these areas because of problems with accessibility (river corridors), destructive sampling (damage to intact biological soil crusts by monitoring teams), and high costs (large number of ground monitoring stations required for a distributed network of high-impact zones). FY2003 funding will be used to contract with a cooperator to evaluate the utility and cost-effectiveness of fine-scale, high-spatial-resolution remote-sensing technologies (including low-elevation aerial photography) for addressing monitoring needs associated with corridors and nodes. The product of this work will be a report which summarizes the results of these evaluations and makes recommendations concerning feasible, cost-effective strategies for high-frequency monitoring of corridors and nodes susceptible to rapid environmental change. This work will be coordinated with the riparian protocol work described above.

At-Risk Species – Threatened, Endangered, and Sensitive (TES) Plants

FY2003 funding has been transferred to NPS to support protocol-development work for monitoring 11 special-status plant species found in Northern Colorado Plateau Network parks (Tables 2 and 3). NPS staff (NCPN) will be responsible for locating a cooperator and coordinating this work.

At-Risk Species – Amphibians

To date, work associated with this vital-sign has focused on the development of protocols for monitoring amphibian populations in association with the Department of Interior's Amphibian Research and Monitoring Initiative (ARMI).

Amphibians serve as good environmental indicators for several reasons: they occupy terrestrial and aquatic milieus and are sensitive to environmental changes in both; because their skin is permeable to both water- and lipid-soluble compounds, they absorb and are affected by pollutants such as pesticides at very low concentrations. These characteristics make amphibians more sensitive to environmental disturbance than many other organisms in ecosystems, making them excellent candidates as vital signs of ecosystem condition.

There have been two major efforts at developing amphibian monitoring programs recently in response to the apparent decline in amphibian populations around the world, and the realization that we have no quantitative data on population condition for most species. However, both the North American Amphibian Monitoring Program (NAAMP), and the work leading to (Heyer et al. 1994), concentrated their efforts on developing methods for mesic environments, methods that work well for the eastern half of this country, montane areas, and the Pacific Coast region. Very limited work has been done in arid or semi-arid regions, particularly in the development of monitoring protocols to track amphibian populations over time across large landscapes. The ARMI program is attempting to explicitly address these problems in the Mojave and Sonoran Deserts (hot deserts), and the Great Basin and Colorado Plateau (cold deserts).

Some Basic Problems

Two significant problems of monitoring amphibians in arid/semi-arid environments are actually determining if an area is amphibian habitat when conditions are right, the limited period of time that amphibians are active in deserts. These are not significant issues in more mesic environments, and have not been dealt with adequately in monitoring protocols that have been developed in these systems.

Identifying Habitat. Desert toads have been found over 300 m vertical distance above cañon bottom breeding habitat, and over 1 km horizontally from known water sources, so adult habitat encompasses vast areas, but encounters are rare. We have decided to concentrate on surveys of breeding habitat (permanent and ephemeral water bodies) to reduce the workload. However, there is a lack of definitive criteria to identify amphibian habitat if amphibians were not actually found at a particular point Is a depression in a channel amphibian breeding habitat if neither water nor amphibians are present? We have spent considerable time over the past few years trying to determine what characteristics define amphibian breeding habitat on the Colorado Plateau. The extended drought has limited our ability to re-visit sites while they contain water and thus be able to establish which sites are actually amphibian habitat. This will be a primary focus of 2004 efforts.

Even if we are successful in characterizing basin parameters that define breeding habitat, we suspect that most of these features are too small to be detected by remote sensors. This makes it very difficult to be able to select survey areas directly using GIS layers; thus, we have resorted to selecting some larger landscape feature, within which all potential habitat patches will be located and surveyed for amphibians.

Activity Period. Amphibian activity in deserts depends on weather; they may not be seen for months, or, in some cases, years, between adequate rainfall events. On the northern Colorado Plateau there are essentially two separate activity periods: spring breeding and development from late March to mid June, and in late July or early August, following the onset of the monsoon season. To estimate Proportion of (habitat patch) Areas Occupied (PAO, MacKenzie et al. 2002), all visits and repeat visits must be made within the same activity period when the probability of detecting amphibians is the same. This means that areas must be surveyed at least twice within spring or summer periods, reducing the time available to make repeat visits that meet both statistical and biological constraints. Because the monsoons are unpredictable in both time and space, it is very difficult to predict where amphibians might be active in this summer season. For this reason, we have chosen to emphasize the spring activity period, with a possibility of summer surveys in certain areas.

ARMI on the Colorado Plateau

The ARMI program has three levels, [see ARMI (2001)and Graham (2001) for definitions of these levels)]: Base Level, Mid Level and Apex Level monitoring efforts. Both Mid Level and Apex

Level areas have been established in Canyonlands National Park, as part of development of amphibian monitoring on the Colorado Plateau.

The Canyonlands Mid-Level Survey Area: Protocol Development

The Colorado Plateau Mid-Level Survey Area (MLSA) was initiated as part of ARMI in 2001, and is focused on Canyonlands National Park and adjacent Glen Canyon NRA and BLM lands to make a coherent Canyonlands MLSA (CANY). NPS Inventory & Monitoring protocol development funds allowed us to extend the field season to explore additional methods and to potentially expand potential mid-level monitoring to include Arches and Capitol Reef National Parks, and Natural Bridges National Monument.

In order to cover large areas of the Colorado Plateau with the available funding, the MLSA was initially divided into smaller units. For the CANY MLSA we used 6^{th} order hydrologic units (HUs).We planned to survey a randomly selected subset of HUs on a rotating four year cycle. Within each HU, at least 20-30 individual habitat patches are required for effective use of PAO, the selected metric for monitoring amphibian populations for each species. Work to date has concentrated on how to select survey areas that 1) allow us to draw inferences about amphibian condition throughout the MLSA (i.e., sites are selected in a probabilistic fashion); 2) can be visited at least twice in a survey period to provide an estimate of detectability needed for PAO estimates; and 3) have some chance of actually containing amphibian habitat.

Second visits and terrain. A major issue, common to all MLSAs with rugged terrain, is that the requirement of multiple visits (at least two) to each potential habitat patch is difficult to accomplish. For example, it may take multiple days of backcountry hiking in areas of limited water to access as few as one or two points; return visits reduce the total number of areas that can be surveyed within the time and funding constraints of the program.

A suggested solution was to conduct the second visits during the same day, or at least the same field session. Our experience indicates this will rarely work because conditions do not typically change rapidly enough to improve detectability of amphibians by the second visit. In more mesic environments, each habitat patch will likely contain water during the first visit, and non-detection of amphibians may be due to true absence, or they were present but not seen or heard. Thus, re-visiting a site within a few hours or days would provide another opportunity to observe amphibians, with roughly the same potential for detection during both visits. In arid environments, however, if the drainage is dry in the morning, it will likely still be dry, in the afternoon, or a couple days later, and any amphibians present would not be detectable because they would be underground. This is a significant issue for cañon country and for rugged mountainous areas, but PAO requires at least two visits to each monitoring site. Possible solutions are to reduce the number of sites, which reduces the accuracy of estimates, or to increase the staff to allow coverage of more areas within the activity period.

Four different survey methods have been used in the quest to find the most efficient and effective approach:

- 2001: Entire Hydrologic Units (HU) surveyed

- 2002: $1km^2$ plots within HU surveyed
- 2002: random points in drainages
- 2003: 500m segments of drainages

Entire HUs. In 2001, we delineated 32 6th order HUs centered on Canyonlands National Park to make up the CANY MLSA. We planned to survey at least three entire HUs each year, at least twice, and to re-visit individual HUs on a four-year rotation. Initially we decided to select three primary and two secondary HUs to be surveyed each year; the secondary HUs were to be surveyed only if there was time after fully covering the primary HUs each year. In 2001, two of the three primary HUs, and ~70% of the third primary HU were surveyed once. Both secondary HUs were completely surveyed one time. These HUs, which range between 4,700ha and 15,650ha, contain remote and sometimes inaccessible terrain, making it impossible to effectively survey these areas at least twice during a season.

One square kilometer plots. In 2002, two survey methods were tested. First, randomly selected 1 km^2 plots, totaling approximately 20 percent of each HU area, within the three primary HUs in the 2001 rotation were surveyed in their entirety. These locations were often remote, making travel time excessive and return visits infeasible. In fact, the logistical problems of reaching these cells were essentially the same as surveying the entire HU.

Random points in drainages. A second survey method was devised to reduce the logistical difficulties of surveying areas, and tried in late summer 2002: random points were selected from the hydrography GIS layer, which are essentially the solid and dotted blue lines of a topographic map. Once at a point, technicians would flip a coin to determine direction, and then walk until habitat was found. This habitat patch was surveyed for amphibians, and habitat characteristics data were collected. This "blue line" selection process was tried only in Arches NP in 2002.

500 m segments in drainages. In 2003, the "blue line approach" was modified and tried in the CANY MLSA, as well as in Arches NP and Natural Bridges NM. Random 500 m segments were selected from 10 percent of the total number of 500 m segments in the MLSA. Since surveying occurred only along drainages, technicians were likely to find more habitat patches in 500 m of drainage per unit search time than searching entire HUs or 1 km^2 cells. This method is more logistically viable from the standpoint of planning and executing surveys, since we can expect that it will be possible to re-visit the segments and habitat patches within them in a timely fashion.

Despite the advantages of using 500 m segments, there are some limitations to this method. Approximately 22% of the segments surveyed in 2003 contained no potential amphibian breeding habitat based on criteria we have developed thus far. This method of selecting survey units explicitly excludes some amphibian breeding habitat and activity: the summer monsoon activity period and breeding cycle is ignored, and any breeding habitat outside of drainages are not included in the universe of potential habitat to be surveyed. Thus, potholes (e.g., rock pools outside of drainages), some stock ponds, swales in undulating topography, and wet meadow pools could not be selected for survey. As a result, inference about amphibian population condition could only be made for drainage populations.

The range of inference has also been limited in other ARMI MLSA studies. For example, in Olympic National Park, only mapped ponds on slopes of less than 30% are included in the selection process. It might be possible to conduct research into the connectivity between drainage- and upland-breeding populations in Colorado Plateau areas, and thus establish whether conditions of drainage-breeding populations reflect conditions of other populations, but this would be a directed research effort, and would entail additional funding. At this time, we should concentrate on establishing a viable monitoring program, and if there are trends that raise some concern, we can pursue the relationship with populations that are not currently being monitored.

<u>Alternative methods to select survey points</u>. Inventory the entire MLSA, identifying all available habitat patches. The set of habitat patches then becomes the universe from which monitoring locations will be drawn. This has a large initial cost, but a major advantage is that all potential habitat patches are available for monitoring, which means that both upland and drainage populations will be monitored, and inference can be made throughout the MLSA. In addition, once potential habitat has been identified, surveys can be more efficient because there will be less search time spent trying to find the habitat; this time can be spent *at* the sites searching for amphibians.

It may be possible to provide adequate data to a GIS that will allow for elimination of portions of a MLSA with no chance of being habitat. For example, evaluation of low-elevation, high-resolution aerial photography for habitat features, and subsequent training of a GIS to recognize aggregates of these features that are likely to be amphibian habitat may provide a relatively accurate universe from which to select monitoring locations.Refine the 500 m segment method of 2003 by providing subjective criteria to stratify the MLSA into areas likely to contain amphibian habitat and areas very unlikely to contain appropriate habitat. For example, use DEM and geology layers to identify large areas with very little slope and no bedrock exposure that are very unlikely to contain amphibian breeding habitat. These areas could be weighted such that the GIS selects 10% (or some other low percentage) of this poor quality habitat to be surveyed. This approach may eliminate some potential habitat, but will direct most effort to areas that have a higher probability of containing amphibian habitat and thus may be more cost effective.

<u>Apex-Level Monitoring at Canyonlands NP</u>

Two Apex Level Monitoring Areas (ALMAs) have been designated in Canyonlands NP in conjunction with ARMI and other research efforts. These are Horseshoe Canyon, and the middle section of Salt Creek within the park.

At Horseshoe Canyon, visual encounter surveys (VES) are conducted weekly (with some gaps), from the onset of toad activity (usually late March) until cessation of toad activity in late September or early October. Numbers of individual adult, yearling and metamorph toads are counted and assigned to size classes, and numbers of eggs and tadpoles estimated, and tadpoles are assigned to size classes. Some surveys were done in 1990 and 1991, work commenced again in 1999, with continuous records since then. *Bufo woodhousii, B. punctatus, Spea intermontana*, and possibly *S. bombifrons* have all been documented in these surveys.

Work in Salt Creek Canyon was started in 2000, and is mostly being conducted in conjunction with studies of amphibian and invertebrate dynamics in relation to the 4WD road in the canyon. In 1998, most of the road was closed to vehicles. In 2000, a total of 16 study sites were established: three in the no road section above the closed road, 10 in the closed road segment, and three in the lower portion of the road still open to vehicles. Amphibian work consists of 16 pitfall traps at each site, run for four nights, and afternoon and evening VES on three transects along the canyon bottom at each site. Fourteen of the 16 sites have been surveyed at least once over the past four years. Data are available for April and June-October 2000, and May-September for 2001-2003. This work is currently funded entirely by USGS, Canyonlands NP, and Earthwatch Institute; none of these sources is projected to continue beyond 2005, thus if this ALMA is to remain active, ARMI and/or additional NPS funding will be needed. *Bufo woodhousii, B. punctatus, Spea intermontana*, possibly *S. bombifrons* and *S. multiplicata,* and *Ambystoma tigrinum* have been documented in Salt Creek surveys.

Stressors – Invasive Exotic Plants

Over the past year the staff developed a framework to organize and depict the relationships among four goals of invasive exotic plant inventory and monitoring in the NCPN parks (Fig. 11). The framework incorporates a tool (the Alien Plant Ranking System) for categorizing and prioritizing invasive species by degree of threat to NCPN resources. Staff efforts have been focused on Prediction, Prevention, and Treatment Effectiveness. Literature pertaining to predicting and monitoring invasions and determining treatment effectiveness has been collected, reviewed (this is an ongoing process), and entered into an EndNote database. Literature and the database will be made available to NCPN parks for purposes of developing weed-management plans.

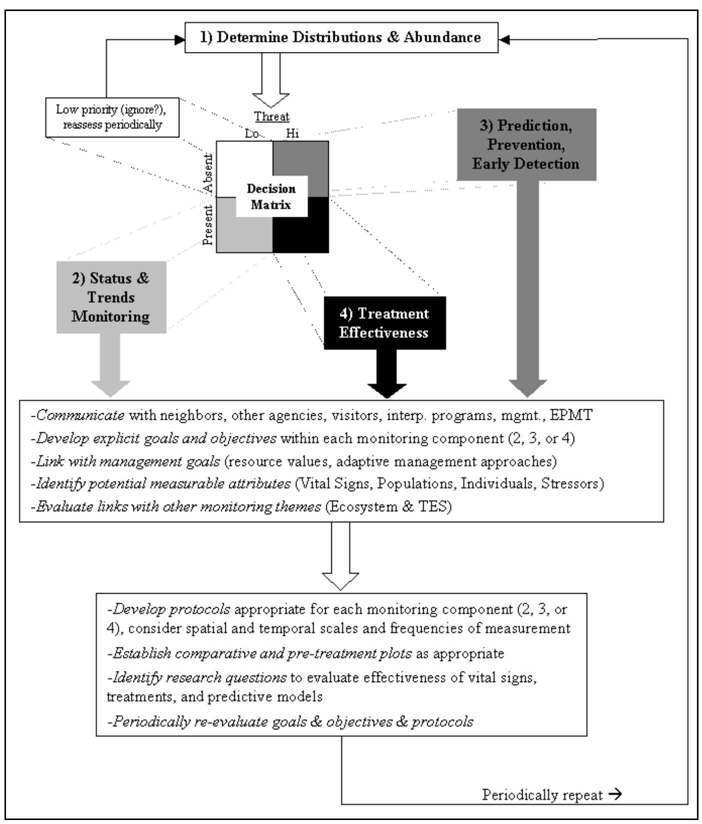

Figure 11. Draft framework illustrating relationships among various aspects of invasive species detection, treatment, and monitoring.

To assist with weed-prevention efforts in NCPN parks, USGS staff have completed a guide with best management practices for activities relevant to wildland management (visitor & personnel awareness, fire and grazing management, and infrastructure construction and maintenance). The guide includes pertinent ecological principles to assist managers in modifying and developing additional BMPs. See Appendix A for the current version of this guide.

USGS staff members also have been collaborating with NPS personnel in the development of invasive plant treatment effectiveness assessments and protocols. This collaboration is focused around a long-term experiment to evaluate different treatments being used (for control of Russian knapweed within Arches NP) and measurements to indicate successful control and ecosystem recovery.

Despite the progress made on invasive-plant protocols over the past year, overall progress was slow relative to initial expectations. This was largely due to the broad scope and complexity of invasive-plant monitoring needs of NPS units (including those outside the NCPN), and the necessity for integrating invasive plant protocols with other aspects of vital-signs monitoring. During FY2004, USGS-BRD will work with NCPN and SCPN to refine the scope and objectives of the invasive-plant component of vital-signs monitoring.

FY2003 Budget Expenditures

FY2003 budget expenditures are reported below in Table 2. Carryover funds not accounted for by the cost-center burden rate (4% overall) will be applied to continued protocol-development work associated with upland soil stability and hydrologic function.

Table 2. FY2003 budget expenditures.

Item / subtask	**Salary**	**Supplies**	**Travel**	**Contracts / agreements**	**Total**
Climatic conditions	10,400				10,400
Upland soil stability / hydrologic function / nutrient cycling	15,160		1190	30,000 (labor + lab analyses)	46,350
Riparian ecosystems	36,400				36,400
Remote sensing applications				35,000	35,000
At-risk species – TES plants				40,000	40,000
At-risk species -- Amphibians	12,500	1000	1500		15,000
Stressors – Invasive exotic plants	18,260				18,260
Carryover					13,590
TOTAL					215,000

III. PROPOSAL FOR FY2004 AND DISCUSSION OF OUT-YEAR PLANS

This section proposes work to be conducted with FY2004 funding, and it discusses FY2003-FY2004 work in the context of out-year plans through FY2007.

Need and Overall Objective

NCPN and NCP Prototype Cluster vital signs were identified in FY2003 through an extensive process involving input from all network parks, an independent scientific review panel, and many other technical experts (Miller et al. 2003). At the network level, 55 broadly defined vital signs were identified. Of these, 34 were determined to be high priority. Together with NPS staff, USGS-

BRD has identified a subset of these high-priority vital signs to include in the FY04-FY07 USGS work plan for indicator-validation research, pilot implementation, and protocol documentation (Table 3). In addition to the general USGS objectives stated above, the overall objective of the work described below is to provide technical support to NPS in the development of a scientifically defensible long-term ecological monitoring program that meets the goals of the NPS vital-signs monitoring program in a cost-effective manner.

Table 3. Actual and projected schedule of USGS support (indicator validation, protocol development, pilot implementation) for the NCP Prototype Cluster, organized by NCPN vital signs and associated measures.

Vital signs	Measures		Funding Year (FY)				
			03	04	05	06	07
Climatic conditions / events							
Precipitation	Daily / seasonal patterns and frequency / magnitude of extreme events		X	X	X	X	
Temperature							
Wind							
Soil, water, and nutrient dynamics							
Upland soil / site stability	Spatially extensive aerial measures	Spatial distribution & density of social trails, animal trails, and vehicular disturbances		X	X		
		Spatial extent of soil disturbances associated with trailheads, campgrounds, and other high-use areas		X	X		
		Cover and structure of live vegetation		X	X		
		Cumulative extent of bare-ground patches		X	X		
	Ground-based measures	Cover and structure of live vegetation; litter and rock cover		X	X	X	
		Bare-ground patches		X	X	X	
		Soil aggregate stability (field index)	X	X			
		Cover of biological soil crusts by morphological group	X	X			
		Soil susceptibility to erosion by wind (dust traps)	X	X	X	X	X
		Soil susceptibility to erosion by water (silt fences)		X	X	X	X
Upland hydrologic function	Spatially extensive aerial measures	Spatial distribution & density of social trails, animal trails, and vehicular disturbances		X	X		
		Spatial extent of soil disturbances associated with trailheads, campgrounds, and other high-use areas		X	X		
		Cover and structure of live vegetation		X	X		
		Cumulative extent of bare-ground patches		X	X		
	Ground-based measures	Cover and structure of live vegetation; litter and rock cover		X	X	X	
		Bare-ground patches		X	X	X	
		Soil aggregate stability (field index)	X	X			
		Cover of biological soil crusts by morphological group	X	X			
		Soil susceptibility to erosion by water (silt fences)		X	X	X	X
		Soil penetration resistance (compaction measure)			X	X	
Upland nutrient dynamics	Ground-based measures	Cover of biological soil crusts by morphological group	X	X			
		Litter cover			X	X	X
		Bare ground			X	X	X
		Soil penetration resistance (compaction measure)			X	X	
Stream flow regime	Ground-based measures	Continuous stream flow / discharge; stream hydrograph characteristics; number and duration of dry periods in streams and rivers; frequency and duration of flow in ephemeral and intermittent channels	X	X	X		
Stream / wetland hydrologic function	Spatially extensive aerial measures	Areal extent of riparian / wetland vegetation	X	X	X		
		Spatial distribution & density of social trails, animal trails, and vehicular disturbances in riparian / wetland zones	X	X	X		
		Composition, structure, and vigor of riparian / wetland plant communities	X	X	X		
		Stream channel morphology	X	X	X		
	Ground-based measures	Composition, structure, and vigor of riparian / wetland plant communities	X	X	X		
		Stream channel morphology	X	X	X		

Table 2 continued.

Vital signs	Measures		Funding Year (FY) 03	04	05	06	07
Biotic integrity							
Status of upland plant communities	Upland vegetation composition / structure (ground-based measures)	Literature review / methods assessment		X			
		Assessment of quantitative repeat-photo methods			X	X	
		Analysis of SEUG long-term veg data	X	X			
		Pilot testing of methods			X	X	
		Protocol write-up (integrated with upland soil / site stability and upland hydrologic function)				X	X
Status of riparian plant communities	Riparian vegetation composition / structure		X	X	X		
Status of biological soil crusts	Cover of biological soil crusts by morphological group		X	X			
Status of aquatic macroinvertebrates communities	Abundance / diversity of macroinvertebrates (ephemeral, intermittent, perennial streams)			X			
Status of amphibian populations	Proportion of area occupied (PAO)		X	X	X	X	
Biotic integrity -- TES plants							
Arizona willow	Population status; habitat condition		X				
Despain's cactus	Population status; habitat condition		X				
Jones' cycladenia	Population status; habitat condition		X				
Last Chance townsendia	Population status; habitat condition		X				
Maguire daisy	Population status; habitat condition		X				
Shivwits milkvetch	Population status; habitat condition		X				
Sye's butte plainsmustard	Population status; habitat condition		X				
Ute ladies' tresses	Population status; habitat condition		X				
Winkler's pin-cushion cactus	Population status; habitat condition		X				
Wonderland Alice flower	Population status; habitat condition		X				
Wright fishook cactus	Population status; habitat condition		X				
Mussentuchit gilia	Population status; habitat condition		X				
Landscape-level patterns							
Land cover Land use Park insularization Fragmentation / connectivity	Spatially extensive aerial measures	To be determined		X	X	X	
Stressors							
Invasive exotic plants	Spatial distribution / extent; relative dominance in plant communities		X		X	X	X
Miscellaneous monitoring support							
Ecological assessments to support monitoring design and implementation					X	X	

Climatic Conditions and Events

Because of their significance for driving multiple ecosystem processes, climatic conditions and extreme climatic events have been identified as high-priority monitoring needs by NCPN parks. During FY2004, USGS and NPS will work together to develop a strategy for climate monitoring that involves at least three tiers – (1) National Weather Service Cooperative Network stations, (2) intensively instrumented automated stations (e.g., wind, solar radiation, precipitation, temperature), and (3) inexpensive single-purpose instruments (e.g., HOBO precipitation event loggers). The strategy will involve coordination with the NPS fire program and integration with the spatial design of plot-based monitoring of soils and vegetation. Spatial products described above in the FY2003 report will be used for purposes of assessing adequacy of existing monitoring and stratification for additional monitoring. During FY2006 and FY2007, a multi-tier spatial design will be developed in conjunction with the design of other monitoring efforts and protocols will be developed following the guidance provided by Oakley et al. (in press).

Upland Ecosystems – Ground-Based Measures

Water Erosion Prediction Project (WEPP) Model Parameterization

Vital Signs: Upland soil / site stability and upland hydrologic function

Measures: Cover of litter, rocks, bare ground and plants; plant structure

The cover of plants, plant litter, rocks, bare ground and plant structure are all important in determining how much soil is lost from a site via wind and water erosion (vital sign: soil stability), and how much water infiltrates locally into soils and how much runs off (vital sign: upland hydrologic function). USDA-ARS has put a great deal of effort into developing the WEPP (Water Erosion Prediction Project) model which is used to determine the amount of runoff water and sediments one can expect from a given watershed. This model is parameterized with information on vegetation cover, ground cover, soils, slope, and climate. In FY04-05 we will contract with a hydrologist to use this model to determine the natural range of runoff and sediment that can be expected from dominant vegetation and soil types in the parks. These results will be field validated (discussed below under measures of aggregate stability, silt, and dust). This model will also be used to determine how much vegetation and ground cover can be reduced before sites (classified by slope and soil type) produce unacceptable levels of water runoff and sediment loss. If site monitoring shows cover values below this threshold, management action (e.g., restoration, fencing) will be required.

We expect two types of products. One will be a parameterized WEPP model that can be used by network personnel and managers to address specific park questions. The second product will be a report outlining the minimum levels of ground and plant cover required for different slopes and soils to maintain acceptable levels of water and sediment loss. Both products should be immensely useful for all arid land networks and will be shared with these networks.

Field Studies of Soil Erosion by Wind and Water

Vital Signs: Upland soil / site stability and upland hydrologic function

Measures: Soil aggregate stability. biological crust development, and soil susceptibility to wind erosion

Soil aggregate stability and the level of biological soil crust development are important measures of how stable soils are at a given site. In FY03, we took already-developed field methods ("Interpreting Indicators of Rangeland Health", BLM Technical Reference 1734-6) that easily and accurately measured soil aggregate stability and adapted them for the soils typical of the Northern Colorado Plateau network. We determined that measuring soil crusts by morphological groups was at a level of detail not needed to assess vulnerability to wind erosion and so instead we developed a much quicker way to visually assess the developmental stage of biological soil crusts. We then tied these two methods to the susceptibility of different soil types to wind erosion. (Details regarding this work are provided above in the FY03 progress report.) In FY04, we will be writing the protocols for field measures of soil aggregate stability, visual assessment of biological crust development, and determining the wind erodibility of surfaces using these two indicators.

In FY04, we will also install dust sediment collectors in key areas throughout the park to document naturally-occurring levels of soil erosion via wind. We have six years of data from collectors in a perennial and an annual grassland on sandy soils that were in place for the extreme drought events of the past 4 years. These will be supplemented by collectors placed in dominant shrub types and on different soil types. This network of collectors will be monitored every six months and be run through FY07.

These measures will be combined with other measures (e.g., compaction) to provide direct information on soil stability, as well as to provide information on the impact of social trails, vehicular disturbance, trailheads, campsites, etc. on soil stability and susceptibility to wind erosion. Products from this effort will include protocols written during FY04 and published scientific papers on what level of soil aggregate stability and biological crust development is necessary to stabilize soils such that soil losses do not exceed natural loss rates (as documented with the dust traps). Because many of the soil characteristics found in the Northern Colorado Plateau network are similar to those in other networks, the results from this project will be shared with these networks and should be of great help in their efforts to measure soil susceptibility to water erosion.

Measures: Soil aggregate stability. biological crust development, and soil susceptibility to water erosion

Soil aggregate stability and the level of biological crust development are also being developed as indicators for the susceptibility of soils to water erosion. During FY 03 and during FY04-05 we will have conducted, and will continue to conduct, experiments using rainfall simulators and silt fences to determine the level of sediment produced under varying degrees of aggregate stability and biological crust development on different soil types. (As with wind erosion, we determined that measuring crust morphological groups was not needed to predict soil vulnerability to water erosion). With the rainfall simulator, we are applying realistic levels of rainfall under these varying conditions and measuring sediment production and runoff. Given the data we have already collected from sandy soils, it is clear that these indicators will work with this soil type. We now need to extend this effort to other soil textures (FY04).

To collect information on the natural range of sediment production from sites with differing soil, soil crust, and aggregate stability characteristics, silt fences will be placed at the bottom of slopes to collect sediment from whole hillslopes (thus avoiding the placement problems encountered with erosion bridges or microwatersheds). These will be established in FY 04 and maintained throughout FY06, thus integrating the site response to many types of naturally-occurring rainfall intensity and amounts. Data loggers are located at these sites so we know the characteristics of the rainstorms.

These measures will be combined with other measures (e.g., compaction) to provide direct information on soil stability, as well as to provide information on the impact of social trails, vehicular disturbance, trailheads, campsites, etc. on soil stability and susceptibility to water erosion.

Products from this completed effort will be similar to those reported for wind erosion in the FY03 progress report and protocols written in FY04. We will show the relationship between aggregate stability, crust cover, and soil susceptibility to water erosion. We will suggest a threshold that should trigger management action. We will also include the natural range of sediment production we measured at the various sites. Because many of the soil characteristics found in the Northern Colorado Plateau network are similar to those in other networks, the results from this project will be shared with these networks and should be of great help in their efforts to measure soil susceptibility to water erosion.

Measure: Soil penetration resistance (compaction)

The permeability of the soil surface determines, to a large degree, local hydrologic cycles. As soil permeability increases, so does the ability of water to infiltrate. Therefore, this measure is important in understanding where and how much precipitation will enter the soil and how much will run off. In FY05 and FY06, we will demonstrate the nature of the link between compaction levels and infiltration rates across a variety of soil textures using a tension infiltrometer. After sufficient measures are made (which needs to be determined for each soil type, depending on the variability encountered), we will write up protocols during FY06. This measure will be combined with other measures to provide direct information on ecological functioning of a site, as well as to provide information on the impact of social trails, vehicular disturbance, trailheads, campsites, etc. on local hydrologic cycles. Products will include written protocols and a scientific paper on how infiltration rates are affected by compaction. This information will be shared with other networks, as it will be of value to their programs as well.

Field Studies of Nutrient Cycling

Vital Sign: Upland nutrient dynamics

Measure: Cover of biological soil crusts by morphological group

It has been well-established in the literature that biological soil crusts are the dominant source of nitrogen for Colorado Plateau ecosystems. However, the type of lichens and cyanobacteria found in the soil crust determines the amount of nitrogen that is fixed and subsequently released into the soil. Therefore, it is important the morphological groups of crusts be distinguished when examining the nutrient dynamics at a site. We have developed methods for measuring the cover of the crust morphological groups during FY03 and will be writing up these protocols during FY04.

It has been established that on sandy soils, plants growing in well-developed lichen crusts have higher elemental content of most plant-essential nutrients than plants growing in bare soil. Therefore, the flora of the crust affects both plant health and forage quality for wildlife. However, we do not know what level of crust development is sufficient to maintain high nutrient levels in the soils and in associated vascular plants. In FY04 and 05 we will find sites with nearby examples of low, medium, and high crust development (reported in the FY03 progress report as Classes 1-2, 3-4, and 5-6) on sites dominated by sand, silt, and clay. At each site, we will sample the same species of dominant grass, forb, and shrub across the three nearby crust types. We will collect all above-ground parts of the plant, and will collect them before they begin to set seed. Because we will be only comparing among the three crust types at a given site, time of collection will not affect our results.

Results from this survey will inform managers what level of crust development is required for plants to have access to adequate levels of soil nitrogen and other nutrients to produce maximal forage quality for wildlife. Products will include sampling protocols for others wishing to repeat this study, but more importantly, a report will be produced that will contain data to give this indicator, biological crust flora, scientifically-defensible ecological meaning. This data will be valuable for other networks and will be shared with them.

Measure: Soil penetration resistance (compaction)

Because the permeability of the soil surface determines the ability of water to infiltrate, it also influences how much moisture is available to soil food webs organisms. This, in turn, affects the decomposition rates of plant materials and the rates of microbially-mediated nutrient transformations. In addition, soil organisms need space in which to live, which is influenced by the bulk density of the soil, which is also measured as permeability. Therefore, this measure can be important in understanding decomposition and nutrient cycling rates. We have demonstrated the linkage between compaction and reduced soil food web organisms in sandy soils. However, we need to do this for other soil textures as well. We will begin this effort in FY05 and finish in FY06. This measure will be combined with others to provide direct information on ecological functioning of a site, as well as to provide information on the impact of social trails, vehicular disturbance, trailheads, campsites, etc. on local hydrologic cycles.

Products from this study will be written protocols and a scientific paper linking compaction with soil food web structure and abundance across a variety of soil types. This information will be of value to other networks, and will be shared with them.

Development of Protocols for Integrated Plot-Based Monitoring

Vital Signs: Status of upland plant communities, status of biological soil crusts, upland soil / site stability, upland hydrologic function, upland nutrient dynamics.

Measure: Upland vegetation composition/structure, ground cover

Integrated plot-based measurements of vegetation, ground cover and dynamic soil properties will be an integral part of the NCPN monitoring program. Plots placed in undisturbed areas will be used to provide information on the range of variation occurring in the vegetative communities, independent of direct human disturbance. These changes can result from many factors, some of which include climate and regional-level nutrient deposition. These plots will also act as references for plots placed in disturbed areas and to provide restoration goals.

There are many ways to measure vegetation in the literature. NCPN needs to study and assess these methods to find the ones that will provide the level of detail needed in the most accurate, precise and cost-effective manner. In FY04, we will collect and read the available studies, with an emphasis on those done in areas where vegetative cover is sparse. In spring FY05, we will conduct field tests of those methods that appear most likely to suit our purposes in a variety of vegetation types. The intent of this field test will be to establish which method to use and the sampling effort that will be required in each vegetation types. In FY06 we will continue this effort and in FY07 we will write up protocols for the preferred method.

We also realize that we will not be able to sample all the vegetation types in all the parks every year. Therefore, we will need to select a subset of vegetation types and develop a timetable for measurements. In order to base these decisions on objective criteria, in FY03 we began analyzing the long-term (14 year) vegetation data set collected from Natural Bridges, Canyonlands, and Arches NP. These 14 years span very wet, very dry, and average precipitation years. Our questions include: (1) Do some communities respond in a very similar fashion across these years (so that one community type might act as a surrogate for several others), (2) is there a correlation between precipitation and the response of particular communities (perhaps we only need to sample certain years), and (3) what and how fast is the response of each community to extremely wet and extremely dry years relative to average years (perhaps we only need to monitor extreme years). We are employing a variety of ordination techniques and multivariate statistics to answer these questions. This effort will continue into FY04. The results of this effort will inform the sampling design for our long-term vegetation plots as well as the design of climate monitoring. These results will also be disseminated via scientific journal articles and to the other arid land networks.

Measure: Biological soil crusts by morphological group

Biological soil crusts are a major part of the biotic diversity found in the NPCN parks. Soil surface disturbance drastically reduces the cover and the biodiversity of these soil crusts. Therefore, their condition needs to be monitored not only as an indicator of soil stability, hydrologic function and nutrient dynamics, but this also needs to be monitored for the crusts as a part of the biological community.

Methods for assessing biological soil crusts by morphological group have been developed. Protocols for this assessment will be written during FY04 and shared with other arid-land networks.

Application of Remote-Sensing Technologies to Long-Term Ecological Monitoring

Vital signs: Upland soil / site stability, upland hydrologic function

Measures: Spatial distribution and density of social trails, animal trails, and vehicular disturbance (low-intensity use). Spatial distribution and density of trailheads, campgrounds, and other high-use areas.

Proliferation of social trails and vehicular disturbance is a major issue for park managers. Measurement of these impacts in low-use areas is especially problematic, as any ground-based efforts will result in undesirable impacts (i.e., the creation of additional social trails). Additionally, ground-based efforts of either low or high use areas is not time-efficient. Therefore, we plan to use airplane reconnaissance to monitor changes in the spatial distribution and density of social trails, animal trails, and vehicular disturbance. We also plan to use a remote platform (whether satellite or airplane) to monitor changes in the spatial distribution and extent of trailheads, campgrounds, and other high-use areas. The FY04 effort will investigate what spatial resolution will be required to measure both disturbance intensities, and what platforms will provide data at a feasible cost. For the low intensity uses, we will compare true color images at 1:24K and 1:7.2K recently acquired by NPS, and digital photos at 1:24K and 1:7.2K that will be acquired through contract by USGS. (FY04 funding will supplement FY03 funding in this effort.) For the high-intensity areas, we will compare the same formats and resolutions as for the low-intensity disturbances, as well as satellite imagery (e.g., Landsat, IKONOS). The ecological meaning of this measure will be documented with additional protocols being developed for other measures discussed above under the vital signs soil stability, upland hydrologic function, and nutrient dynamics: compaction, soil aggregate stability, and cover of biological soil crusts, litter, rocks, bare ground and plants.

A second part of this effort during FY04 will be the write-up of protocols already developed for determining whether or not social or animal trails are currently being used and if not, recovery rates of these trails.

This effort will begin in FY04 and continue through FY05. This effort will result in a protocol for monitoring these different disturbance levels that will outline what format, what resolution, what platform, and what frequency of data collection are best suited for the Northern Colorado Plateau parks. We will share the results of this investigation with other arid-land networks. However, it should be noted that because we have heavy biological crust cover in most areas of these parks, detecting disturbance change in low-intensity areas will probably employ different methods than those required for most other networks.

Riparian Ecosystems

Vital Signs: Stream flow regime, stream / wetland hydrologic function, and status of riparian / wetland plant communities.

Work for FY04 would involve implementing a pilot of the monitoring protocol at 3-5 of the chosen field sites, including site set-up, data collection, analysis, and reduction. Because riparian ecosystems are structured and maintained by fluvial geomorphic disturbance events, monitoring of riparian vegetation should necessarily be tightly integrated with measurements of flow variability and associated geomorphic change. Thus, the basis of our proposed monitoring approach involves establishing permanent transects within a study reach. A reach is defined as a discrete hydrologic and geomorphic unit, such as a debris fan-eddy complex in a bedrock canyon. Stage and discharge relations will be developed at the site using pressure transducers to record stage over time and relating these measurements to discharge records at the nearest USGS stream gages. Repeat topographic surveys of geomorphic surfaces, from waters edge to the upland boundary, will be used to track changes in geomorphic surfaces. Finally, the composition and structure of riparian vegetation will be monitored in plots, centered on and located along, the permanent transects. In this way, cause and effect relations between flow, geomorphic change and riparian vegetation dynamics can be monitored over time. Monitoring results from intensive sample reaches could be extended to similar reach types using aerial photography and other remotely sensed data.

We would plan to implement pilot testing of the protocol at the field sites in the Summer of 2004 and 2005. This would result in a report describing the protocol and presenting a detailed outline of how to implement, maintain and interpret the results of a program to monitor the structural and functional integrity of riparian vegetation in a variety of fluvial geomorphic settings typical of the Colorado Plateau physiographic province.

Plans in out years (e.g., FY05) would be to expand the monitoring protocol to additional sites and geomorphic settings and explore the possibility of incorporating additional monitoring elements, such as riparian birds and aquatic macroinvertebrates, into a more broadly integrated monitoring protocol. Finally, we would plan to publish details of the protocol and the monitoring results as one or more applied research papers in peer-reviewed journals.

Aquatic Macroinvertebrate Monitoring (streams)

Stream macroinvertebrates are often used as integrated indicators of stream quality (sediments, nutrients, and pollutants). Although there are protocols available for measuring aquatic macroinvertebrates, none have been developed specifically for arid-land perennial, intermittent, and ephemeral streams found on the Colorado Plateau. Accordingly, we need protocols developed for these types of habitats. This work will be conducted by an aquatic ecologist with USGS-WRD in Salt Lake City. The sampling design will be coordinated with the riparian monitoring design being developed by USGS-BRD in Fort Collins, the water-quality monitoring design being developed by USGS-WRD in Grand Junction, and the development of spring-seep monitoring protocols by cooperators jointly funded by NPS NCPN and SCPN. This work will expand on a limited macroinvertebrate component included in the water-quality design work conducted by Grand Junction USGS-WRD. The task would be to evaluate and modify existing protocols as appropriate, to pilot-test these protocols on a selected subset of NCPN waters, and then to write protocols consistent with guidance provided by Oakley et al. (in press). This task would be started and finished in FY04.

FY2004 work will include:

- Reconnaissance of various potential sampling sites (to confirm the types of habitats available and to refine the specific sampling techniques recommended)

- Evaluation of invertebrate metrics currently in use in the region, and assessment of the usefulness of these metrics for NCPN parks;

- Production of a USGS Administrative Report summarizing results of the reconnaissance efforts and the evaluation of existing metrics, and expansion on the initial report provided as part of the water-quality monitoring design being developed by USGS-WRD in Grand Junction. Additional information detailing sampling techniques, required supplies, identification protocols, etc. (that are not covered in the water quality report) will be provided.

- Preliminary sampling (and sample identification at an established lab) at selected sites to validate sampling techniques and to provide some baseline data.

- Statistical analysis and interpretation of this data , which will also provide a template for analyzing data collected during the actual monitoring.

- A more detailed sampling protocol to guide activities during the monitoring activities.

- Other potential products could potentially include a GIS component, creation of data sheets for use in the field, or other items as requested.

At-Risk Species – Threatened, Endangered, and Sensitive (TES) Plants

NPCN has 11 listed plants that the parks are required to monitor. The network will provide these parks protocols for assessing the population status and habitat condition for these plants. This will be done by first "embedding" these plants in the national TES framework developed by the Nature Conservancy and USFS. This framework provides general guidelines for monitoring annual and perennial herbs, grasses, and shrubs. We will then provide the parks more specific information regarding the species that they are required to monitor. This effort was begun in FY03 and will be finished with FY03 funds. The products from this effort be written protocols for these species.

At-Risk Species – Amphibians

Amphibian populations are declining in a wide variety of habitats around the world. In spite of this, very little is known about amphibians on the Colorado Plateau. In some areas, the number and identity of species present are not even known. Because amphibians are very sensitive to many environmental disturbances, they make good indicator species for monitoring conditions of ecosystems, and thus would be useful in the context of the Northern Colorado Plateau Network Vital Signs Monitoring program.

Objectives of this effort are:

1) To develop methods for monitoring amphibian populations in the NCPN, preferably in a way that allows collaboration with the DOI Amphibian Research and Monitoring Initiative (ARMI) efforts to maximize cost efficiency and relevance of the data.
2) Evaluate feasibility of using the "blue line layer" approach to designate sample units in the context of surveys to determine proportion of areas occupied (PAO, Mackenzie et al. 2002).
3) Select segments to be established as monitoring sites for at least the first year in a four-year rotation in the Canyonlands MLSLA.
4) Survey first year's segments at least two times, at least two weeks apart during appropriate conditions for amphibian activity, for presence of amphibians and potential amphibian habitat.

The "blue line approach" was modified and tried in the Canyonlands MLSA, as well as in Arches NP and Natural Bridges NM in 2003 (described above in FY2003 report). Consultations with statisticians led to selection of 500 m segments of drainages rather than of a point. Within each 500 m segment, all patches of potential amphibian habitat were located, georeferenced, searched for amphibians, and habitat parameters measured and documented. The unit for estimating proportion of areas occupied (PAO) will be the segment, but the number of habitat patches may be used as a covariate in analyses, and habitat analysis will also be conducted at the patch level. Protocol development funds will also allow us to expand our efforts in Arches NP and Natural Bridges NM, and begin to evaluate the feasibility of incorporating Capitol Reef and possibly other NCPN units into the final monitoring design. Monitoring of Canyonlands districts will be scheduled to coincide with park water quality monitoring schedules.

Amphibians become active as soon as air temperatures are consistently above 10-15°C in the spring, and breeding commences as early as late March or early April. Preparations for fieldwork (selection of monitoring segments, acquisition of equipment, etc.) will begin in early March 2004, and surveys will begin as soon as weather permits. All re-surveys should be completed by late June, with the most ephemeral habitats surveyed first, more permanent habitats can be surveyed during hotter, drier periods.

Expected results include data on presence/not detected condition of each habitat patch and each 500 m segment in the first year monitoring scheme in the Canyonlands MLSA and PAO estimates, data on habitat characterisitcs, correlated with presence/non detection of each amphibian species, summarized data for Horseshoe Canyon and Salt Creek Apex sites, and analyses of habitat parameters that appear to be critical for each amphibian species in each park unit.

NPS Superintendents and Resource Managers in sampled parks will be able to use data from this amphibian monitoring program to evaluate current condition of amphibian populations in their parks, and over time, determine population trends. Habitat information will be valuable as pressures on Park resources continue to mount. Visitor use, maintenance activities, and other Park actions can be evaluated in light of the needs and condition of amphibians in the parks.

The proposed budget (Table 5) will allow for additional areas to be surveyed, including expanding coverage from just the Canyonlands MLSA to other prototype Park units, and also provide additional time for data management and analysis.

Out-year plans – The tentative plan is for 2004 to be the first year of actual monitoring effort in the Canyonlands MLSA, thus in out years, monitoring would continue on the proposed rotation of areas (e.g., Needles, Maze, Island, River Districts). It is anticipated that additional refinement of the selection method, evaluation of the minimum number of segments required, and the minimum number of visits to each segment will be needed and adjustments tested in subsequent years for other Park units, given differences in park shapes and configuration relative to landscape hydrography. For example, southern Capitol Reef may not contain very many drainage segments that are accessible and at least 500 m long, thus methods may need to be revised somewhat. In FY2005, USGS and NPS will work together to evaluate the feasibility of expanding amphibian monitoring to other prototype parks. In FY2006, protocols will be documented following guidance provided by Oakley et al. (in press).

Landscape-Level Patterns

Monitoring landscape-level indicators is vital to any monitoring program. However, identifying what indicators to use has been very difficult for NCPN. Exacerbating this problem is that fact that the distribution of vegetation communities in these arid land parks is determined by soil characteristics and thus communities are not able to move in response to climate changes. Consequently, traditional measures such as ecotone movement will not work in these areas. Traditional measures of urban encroachment or habitat fragmentation by agricultural fields will be insufficient for monitoring impacts of adjacent land uses on park ecosystems because most parks are bounded by BLM lands where livestock grazing and recreation are the predominant land uses.

NCPN has identified several candidate indicators, including vegetation patch size, patch heterogeneity, and the fragmentation or connectivity of different patch types, land uses in and outside the parks, and park insularization. We need to evaluate whether these indicators are appropriate for Colorado Plateau parks and if so, to determine the best ways to measure them. More importantly, we need to determine how to evaluate mechanistic linkages between measured landscape-level patterns and ecological processes in and around parks. We would like to contract with a landscape ecologist to focus on these issues and to develop a strategy for developing a landscape-level component in the NCPN monitoring program. This effort will begin in FY04 and continue through FY06. This effort also will be coordinated with the SCPN and with NPS WASO efforts.

Stressors – Invasive Exotic Plants

In FY03, we supported efforts to develop an informational database on the invasive plants of concern to NCPN parks. The network will use this database to develop the types of monitoring questions they would like addressed by the USGS program. USGS will work with NCPN and SCPN during FY04 to refine monitoring questions relating to invasive exotic plants. In FY05, we will begin protocol development for these questions.

Miscellaneous Monitoring Support – Ecological Assessments

One of the goals of NPS vital-signs monitoring is to "provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management" (http://science.nature.nps.gov/im/monitor/). This goal is closely tied to the "impairment" concept as derived from the NPS organic act. To provide early warning of adverse ecological changes, sampling designs should be developed so that monitoring is conducted where and when the probabilities (or *risks*) of rapid and/or irreversible ecological changes are greatest. Sampling designs that are strategically stratified on the basis of *risk* can be aided by information provided by *ecological assessments*. Ecological assessments use multiple sets of biophysical data to evaluate the relative social and ecological value of ecosystems, the existing status or condition of ecosystems (defined on the basis of vital signs such as soil stability, hydrologic function, biotic integrity, and disturbance regime) *and* the risk of that status changing to a less healthy state (Whitford 1998). Condition (or "health") is described or quantified in relation to benchmark conditions identified at extant reference areas or in studies documenting the historic range of variability. Information provided by ecological assessments is synthesized and used to inform the development of a monitoring design which cost-effectively maximizes the ability of the monitoring program to support pro-active, pre-emptive resource-management decisions.

Currently, USGS is working with NCPN and SCPN to evaluate the need for ecological assessments to support the design and implementation of vital-signs monitoring. Potential USGS roles include the development of an overall approach (or *protocol*) for conducting ecological risk assessments to inform monitoring designs, and assisting in the coordination of field data-collection efforts associated with assessments. Additional information concerning the concept of ecological assessments is provided in Appendix B.

Work schedule

Table 4. General schedule of work for FY2004.

Item / subtask	Month											
	O	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**
WEPP model parameterization								X	X	X	X	X
Field studies of soil erosion by wind & water					X	X	X	X	X			
Field studies of nutrient cycling					X	X	X	X	X			
Protocols for integrated plot-based monitoring	X	X	X	X	X	X	X	X	X	X	X	X
Application of remote-sensing technologies		X	X	X	X	X	X	X	X	X	X	X
Riparian ecosystem protocols		X	X	X	X	X	X	X	X	X	X	X
Aquatic macroinvertebrate protocols					X	X	X	X	X	X	X	X
Amphibian protocols						X	X	X	X	X	X	X
Landscape-level monitoring								X	X	X	X	X

Proposed FY2004 Budget

Table 5. Proposed FY2004 budget.

Item / subtask	Salary	Supplies	Travel	Contracts / agreements	Total
$195,000 budget (based on FY2003) funding					
WEPP model parameterization				20,000	20,000
Field studies of soil erosion by wind & water	25,000	5,000			30,000
Field studies of nutrient cycling	29,750	250			30,000
Protocols for integrated plot-based monitoring	24,000	250	750		25,000
Application of remote-sensing technologies				15,000	15,000
Riparian ecosystem protocols	13,250	250	1500		15,000
Aquatic macroinvertebrate protocols	35,340	6000 (includes sample analyses)	3600		45,000
Amphibian protocols	12,500	1000	1500		15,000
TOTAL					**195,000**
Additional funds requested					
Strategy for landscape-level monitoring				40,000	40,000
TOTAL					**40,000**

NPS Cost-Share Contributions

Several NPS-funded activities will contribute to USGS protocol-development work described above. Particular subtasks with NPS cost-share contributions include WEPP model parameterization and field studies of soil erosion (suppored by soil-mapping efforts), protocols for integrated plot-based monitoring (supported by continued acquisition of vegetation monitoring data by Canyonlands, Arches, and Natural Bridges), application of remote-sensing technologies (supported by aerial photo acquisition), aquatic macroinvertebrate protocols (supported by NPS-WRD funding for water-quality work), and amphibian protocols (likely to be supported by additional direct funding from NPS). Total NPS cost-share contributions for FY2004 are likely to exceed $100,000.

IV. LITERATURE CITED

Amphibian Research and Monitoring Initiative Task Force (ARMI). 2001. *Conceptual design and implementation guidance for the Amphibian Research and Monitoring Initiative*. U.S. Geological Survey, Reston, VA. 60 pp.

Barger, N. 2003. *Biogeochemical cycles and nitrogen dynamics of biological soil crusts in a semi-arid environment*. Unpublished dissertation, Colorado State University.

Belnap, J., and D. A. Gillette. 1997. Disturbance of biological soil crusts: Impacts on potential wind erodibility of sandy desert soils in southeastern Utah. *Land Degradation and Development* 8: 355-362.

Belnap, J., and D. A. Gillette. 1998. Vulnerability of desert biological crusts to wind erosion: the influences of crust development, soil texture, and disturbance. *Journal of Arid Environments* 39: 133-142.

Evans, R. D., and J. R. Ehleringer. 1993. A break in the nitrogen cycle in aridlands? Evidence from $\delta^{15}N$ of soils. *Oecologia* 94: 314-317.

Graham, T.B. 2001. *Amphibian Research and Monitoring Initiative – Canyonlands monitoring area: Protocol-development efforts, 2001*. U.S. Geological Survey, Moab, UT. 16 pp.

Herrick, J. E., W. G. Whitford, and M. Walton. 2001. Field soil aggregate stability kit for soil quality and rangeland health evaluations. *Catena* 44: 27-35.

Heyer, W.R., M.A. Donnelly, R.W. McDiarmid, L.-A.C. Hayet, and M.S. Foster. 1994. *Measuring and monitoring biological diversity: Standard methods for amphibians*. Smithsonian Institute Press, Washington, D.C. 364 pp.

MacKenzie, D.I., J.D. Nichols, G.B. Lachman, S. Droege, J.A. Royle, and C.A. Langtimm. 2002. Estimating site occupancy when detection probabilities are less than one. *Ecology* 83:2248-2255.

McKenna-Neuman, C., C. D. Maxwell, et al. 1996. Wind transport of sand surfaces crusted with photoautotrophic microorganisms. *Catena* 27: 229-247.

Miller, M.E., D. Sharrow, and L. Cudlip. 2003. Northern Colorado Plateau Vital Signs Network and Prototype Cluster Plan for Natural Resources Monitoring, Phase II Report. National Park Service, Northern Colorado Plateau Network, Moab, UT. 111 pp. plus appendices.

Oakley, K. L., L. P. Thomas, and S. G. Fancy. In press. Guidelines for long-term monitoring protocols. *Wildlife Society Bulletin*.

Whitford, W. G. 2002. *Ecology of desert systems*. Academic Press, San Diego.

APPENDIX A. NCPN INVASIVE PLANT PREVENTION GUIDELINES AND BEST MANAGEMENT PRINCIPLES

Prepared by:

Richard Alward, USGS-BRD

17 September 2003 WORKING DRAFT

Acknowledgments

This guide is a compilation of several available lists and recommendations; however, it draws most heavily from Janet Clark's chapter on "Prevention" in the Center for Invasive Plant Management's ***Ecological Invasive Plant Management Textbook****. (Her chapter was largely adapted from the USDA Forest Service "Guide to Noxious Weed Prevention Practices.") Other sources included the Colorado Integrated Weed Management Plan, Partner's Against Weeds (PAWs) Action Plan for the Bureau of Land Management:* ***Integrated Weed Management Guidelines****, the USFS Lolo National Forest Plan* ***Noxious Weed Mgt. Amendment****, and the CIPM's* ***Guidelines for Coordinated Management of Noxious Weeds****. Additional sources are listed in Section V. Thoughtful comments on earlier drafts were provided by Mark Miller (USGS), Beth Newingham (USGS), Tamera Minnick (Mesa State College), Denise Louie (NPS) and Tamara Naumann (NPS).*

I. Introduction

Invasive exotic plants are a concern to wildland managers throughout the world. Such plants are a threat to biodiversity (only habitat destruction is a greater threat) and interfere with management goals. Furthermore, left uncontrolled, invasive exotic plants are an impossible hurdle for the manager attempting to adhere to the National Park Service mission "to conserve the scenery and the natural and historic objects and the wildlife therein, and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for future generations." An **exotic** (or alien) plant is a species that is not native in a particular geographic location, and whose arrival in this new location came about through the intentional or unintentional activities of humans. An **invasive exotic plant** is a species that can subsequently expand its population (and distributional range) and displace native species, without further human intervention (from Usher 1991). The negative consequences of invasive exotic plants are numerous. Invasive exotic plants can alter (1) community species composition (to the point of displacing native species and becoming the new dominant species), (2) natural disturbance regimes (including those of fire, wind and water erosion, and grazing), (3) the height of water tables and surface flow in ephemeral streams, (4) the abundance and distribution of soil nutrients, as well as (5) the primary production of natural systems, as compared to similar, non-invaded systems. The actual ecological effects of these plants vary depending upon the characteristics of the invader itself as well as attributes of the invaded ecosystem.

By far, the most cost-effective strategy for minimizing impacts of invasive exotic plants to natural ecosystems is to *prevent* their initial establishment and spread. The purpose of this document is to provide on-the-ground park staff with information and guidance that may be used to aid the development of a proactive, park-based invasive-plant prevention program. Following the introduction, the document is organized in five sections. The first of these presents background information intended to place preventative practices in the context of an *overall framework for invasive plant monitoring*. The second section provides a brief overview of *ecological principles* pertinent to the prevention and management of exotic plant invasions. The third section focuses on interpretation, education, signage, and other activities that will help prevent exotic plant invasions by *increasing human awareness*. The fourth section presents a suite of *best management practices* intended to ensure that NPS management activities do not facilitate the establishment and spread of invasive exotic species. Finally, the last section provides park staff with additional resource materials (e.g., invasive plant websites, sample brochures) that may be useful in the development of invasive-plant prevention programs.

Background -- Framework for Invasive Plant Monitoring

In June 2002, NPS land managers, and others, participated in a workshop to identify common goals, objectives, and guidelines for invasive plant assessment, inventory, and monitoring. The threat of invasive exotic plants is one of the three emphasis areas of the NPS Natural Resource Challenge. This workshop was due, in part, to the agreed importance of this emphasis among NPS managers and recognition that common approaches would best facilitate responding to the challenge. The participants evaluated numerous inventory & monitoring guidelines developed by government agencies and university researchers and made a summary of the workshop's efforts available online at www.nature.nps.gov/im/monitor.

Effective management of invasive exotic plants requires clearly stated goals from which can be developed measurable objectives. The workshop participants emphasized that the goals of invasive exotic plant management went beyond just treating and killing invasive populations. The goals of all NPS managers should include "protecting and/or restoring the function, structure, and composition of the systems NPS is entrusted to manage." To this end, the workshop participants identified the following four common goals for invasive exotic plant management:

Goals for Invasive Exotic Plant Inventory & Monitoring

- Determine the distribution and abundance of known plant species within and around parks. Assess which plants are present and which have a high potential to be invasive.
- Determine the status and trends of plant invasions over time and space and develop predictive capabilities to better guide future monitoring and management efforts.
- Prevent, predict, detect, and eradicate new alien plant invasions
- Evaluate the effects of management actions on targeted plant species and the ecosystems that they have invaded and determine whether strategic goals have been accomplished.

In January 2003, the NCPN Technical Committee agreed that the above four goals should be adopted for invasive exotic plant inventory and monitoring efforts within the network parks and monuments. The NCPN Invasive Exotic Plant Monitoring Framework (Fig. A-1) serves to graphically and logically organize these four goals and to assist in identifying appropriate management objectives and activities based on the threat that exotic species place on natural resources. The first goal of a monitoring program is to describe the distributions and abundance of the species of concern. This is achieved through a thorough inventory and mapping program. In recognition that managers' (and the network's) resources are limited, actual monitoring efforts will need to be prioritized. These priorities should recognize both the threats imposed by the invasive exotic species as well as the value of the park's natural resources that are being threatened. Thus, the next step is to evaluate the proximity and severity of a potential threat through the use of a combination of expert knowledge and a ranking tool (such as the Alien Plant Ranking System, available through the Southwest Exotic Plant Information Clearinghouse, SWEPIC). The 2×2 grid in the center of Fig. A-1 is a simplification of the output of the results of ranking species identified in Goal 1.

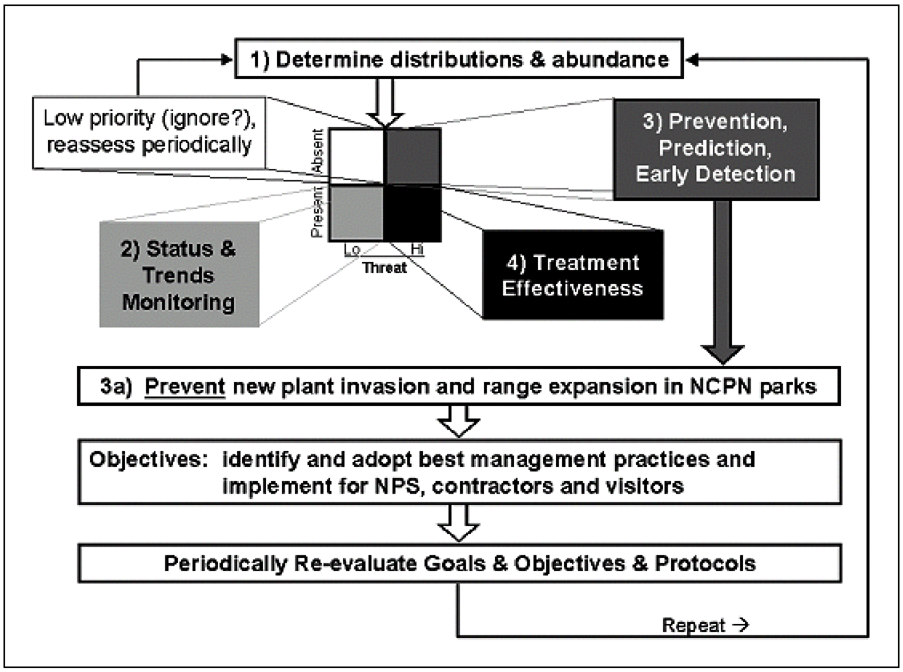

Figure A-1. The NCPN Invasive Exotic Plant Monitoring Framework, emphasizing Goal 3a.

Based on the ranking output, exotic plant species known to have invasive characteristics when established in the region or site of concern (e.g., plants that can displace intact native vegetation or otherwise pose a significant threat to valuable natural resources) and identified as currently absent from a park or site, would direct the manager to adopt appropriate objectives and protocols that follow from Goal 3 (Prevent, predict, detect, and eradicate new invasions).

By far, the most effective, economical, and ecologically sound method of managing invasive exotic plants is to prevent their invasion in the first place. Often landowners and land managers pour resources into fighting weed infestations after they are firmly established. By that stage, ongoing control is prohibitively expensive and eradication is probably not an option (Fig. A-2). Resources might be more efficiently used in proactive weed management activities. Of course, proactive weed management relies on management of existing infestations, but the strongest focus should be on prevention or early detection of new invasions.

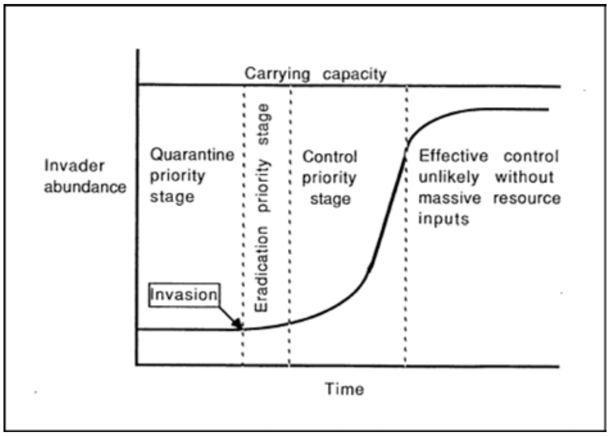

Figure A-2. Phases of exotic plant invasion and priorities for action at each stage. Tremendous resources are required, and control unlikely, if a manager waits too long to act. However, significant resources are also required to detect small populations typical of the early invasion phase. By far, prevention is the least costly method (from Hiebert et al. 2002, Hobbs 1995).

Over 300 exotic plant species can either be found currently in NCPN parks and monuments, or are an imminent threat to the region either because they are found in the region, but outside of parks, or are included on state noxious weed lists even though they currently have not been found in the region (see Additional Materials and Information section). From this long, and continually expanding list, thirty-seven invasive exotic species have been identified by park staff as particular concerns due to current rates of increase, difficulty of control, and the significance of resources impacted (Table A-1).

Table A-1. Invasive exotic plant species of greatest concern to NCPN parks and monuments.*

Trees and shrubs	**Perennial forbs**	**Annual / monocarpic forbs**
Ailanthus altissima (Tree-of-Heaven)	*Cardaria draba* (Whitetop)	*Arctium minus* (Common burdock)
Elaeagnus angustifolia (Russian olive)	*Centaurea diffusa* (Diffuse knapweed)	*Carduus nutans* (Musk thistle)
Tamarix ramosissima (Salt cedar, Tamarisk)	*Centaurea maculosa* (Spotted knapweed)	*Centaurea solstitialis* (Yellow starthistle)
Ulmus pumila (Siberian/Chinese elm)	*Centaurea repens* (Russian knapweed)	*Cirsium vulgare* (Bull thistle)
Perennial grasses	*Centaurea squarrosa* (Squarrose knapweed)	*Cynoglossum officinale* (Houndstongue)
Bromus inermis (Smooth brome)	*Cirsium arvense* (Canada thistle)	*Halogeton glomeratus* (Halogeton)
Dactylis glomerata (Orchardgrass)	*Convolvulus arvensis* (Field bindweed)	*Hyoscyamus niger* (Black henbane)
Festuca arundinacea (Tall fescue)	*Euphorbia esula* (Leafy spurge)	*Melilotus alba* (White sweet clover)
Phleum pratense (Timothy)	*Lepidium latifolium* (Perennial pepperweed)	*Melilotus officinalis* (Yellow sweet clover)
Poa pratensis (Kentucky bluegrass)	*Linaria genistifolia* ssp. *dalmatica* (Dalmatian toadflax)	*Onopordum acanthium* (Scotch thistle)
Annual grasses	*Linaria vulgaris* (Yellow toadflax)	*Salsola iberica* (Russian Thistle; Tumbleweed)
Bromus rigidus (Ripgut brome)	*Marrubium vulgare* (White horehound)	*Tragopogon dubuis* (Goatsbeard; Salsify)
Bromus tectorum (Cheatgrass)	*Sonchus arvensis* (Marsh sowthistle)	*Verbascum thapsus* (Common mullein)

*Adapted from Table 19, p. 59, in Evenden, et al. 2002.

Elements of a *proactive* invasive exotic prevention plan include: limiting exotic plant seeds into an area; early detection and eradication of small patches of exotics; proper management of vegetation along roadside, trails, and waterways; land management practices that build and maintain healthy communities of native and desirable plants that compete well against exotics; careful monitoring of high-risk areas; and annual evaluations of the effectiveness of the prevention plan so appropriate adaptations can be implemented the following year.

Successful prevention programs for managed wildlands such as those encompassed by the NCPN parks and monuments require (1) efforts to increase awareness of this threat among visitors, contractors, and NPS personnel and (2) efforts on the part of managers to identify and implement a program of Best Management Practices. This guide has been produced to assist managers and resource specialists in these efforts and it is organized around the varying objectives that may be more or less appropriate for success in these different efforts.

The remaining four sections in this guide were developed to assist managers and resource specialists in their efforts towards meeting Goal 3 by increasing the likelihood that:

Visitor, contractor, and NPS personnel activities do NOT enhance opportunities for the spread of invasive exotic plants in and around NCPN parks and monuments.

The next section is a brief summary of the ecological principles that inform our current understanding of the processes that underlie exotic plant invasions. In short, plant invasions are just a special, and worrisome, aspect of plant succession. Likewise, effective restoration and repair of ecosystems following removal of invasive exotics should exploit the processes underlying natural plant succession. The goal with presenting this summary is to assist managers in evaluating existing Best Management Practices and/or developing additional ones for the particular situation that the manager is trying to remedy. Even if this summary serves merely to help a busy manager more clearly communicate with biological specialists, the goal will have been met.

Section III includes suggestions for interpretation, education, signage, and other activities that will help to increase awareness of means for preventing exotic plant invasions among visitors, contractors, and NPS personnel. In some cases extensive, long-term, education efforts may be necessary (e.g., to encourage visitors to view NPS lands as dynamic, ever-changing ecosystems, as opposed to being static, unchanging entities). In other cases, simply providing an easy means for the concerned visitor to dispose of seeds found in her socks may greatly reduce the distribution of exotic invasive plants into backcountry campsites.

Section IV presents Best Management Practices that are appropriate for different activities and divisions with NPS. These lists should be made available to the appropriate supervisors and specialists, or the people who are responsible for performing these functions, including the maintenance supervisors, botanists, fire specialists, and biologists. These lists of practices should be considered for all projects, during the planning stages if at all possible, however it is unlikely that all practices will be implemented in every project.

Section V includes additional materials that managers and resource specialists may find useful: citations for the literature consulted to develop this guide, lists of exotic plants threatening the NCPN, links to useful exotic plant internet resources, as well as examples of relevant programs, standards, contract language, brochures and signs.

II. General Ecological Principles Pertinent to Invasive Plant Prevention

This section is a brief introduction to the pertinent ecological principles behind exotic plant invasions. An understanding of the mechanisms of invasions can assist land managers to evaluate Best Management Practices [BMPs] and understand how BMPs can reduce the rates of invasions. This knowledge can be used to guide development of site- or activity-specific BMPs that are not explicitly addressed in the remainder of this document. Busy managers may want to use this section as an aid in communicating with biological specialists.

Natural biological communities and ecosystems are dynamic. That is, they do not reach one state and remain there. Plant community composition may change from year to year, even in communities that are not invaded. It takes only a few measurements to be able to detect seasonal and annual changes in plant species abundance, growth rates, and flowering of different species, and the number of species in an area. This perspective (the dynamic nature of ecological systems) encourages the manager to recognize that change is to be expected and that the manager should strive to direct and manage change rather than prevent it. Random or fluctuating changes in species abundance are termed *vegetation change*. These changes often track variations in annual precipitation, fires, tree falls, herbivore population cycles, etc. In general, the dominant species remain dominant and rare species remain rare in the face of these random changes.

In contrast, *succession* is the directional change in plant species composition over time that extends over many growing seasons. During succession, species that were prevalent early become less abundant and species that initially were rare or absent become dominants in the community. This directional change is driven by processes that make the environment less suitable for the dominant species and more favorable for other species. These processes may be geophysical or biological.

It is often useful to distinguish between two types of succession. *Allogenic succession* is the result of changing external geophysical conditions. (e.g., disturbance frequency, climate change, erosion, and silt or salt accumulation). If the climate in an area becomes warmer and drier, then the plants that dominate the community increasingly will be those that can best tolerate these conditions. The plants that were dominants when the climate was cooler and wetter will decrease in abundance. It is important to recognize allogenic processes because there may be little a manager can do but assist the change in the plant community in a desired direction. *Autogenic succession* occurs as the result of biological processes modifying conditions and resources. Some examples are plants that grow taller and cast shade on other plants, or plants that release chemicals into the soil that inhibit growth of other species, or plants that produce many roots near the surface and help stabilize soils, allowing for other species' seeds to germinate.

New successional processes are initiated when events result in increased availability of resources (e.g., nutrients, water, space) for a vegetation community. Succession initiating events may be classified as either disturbances or stressors. A *disturbance* is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability [i.e., space] or the physical environment (White and Pickett 1985) and are of a magnitude and frequency within the evolutionary history of the ecosystem (e.g., monsoons, drought, fire). For comparison, a *stressor* is an anthropogenically-induced event that is outside the range of disturbances naturally experienced by the ecosystem (Whitford 2002).

A disturbance or stressor may result in increased resource availability by either an increase in supply or by a decrease in consumption. In dry and/or low nutrient ecosystems, an unusually wet season (disturbance) or nutrient additions by way of pollution or fertilizer application (stressor) results in an increase in supply of important resources. For example, a wet season may provide more water than the naturally sparse vegetation can consume. This excess water can then be exploited by exotic species to increase in abundance and become a larger component of the community. On the other hand, a drought (disturbance) or herbicide application (stressor) may kill plants. This results in an increase in the availability of soil nutrients and space due to a decline in the rate of consumption of these resources.

Typically, land management activities may cause multiple disturbances and/or stresses. For example, management may construct a ditch in order to divert runoff water away from roads or buildings. The creation of the ditch is a stressor that involved scraping off plants and soil, creating new bare soil (space) that may be colonized by native or exotic species. Additionally, the water that is redirected by the ditch accumulates elsewhere resulting in an abundance of water somewhere else in the ecosystem.

Exotic plant invasions are just a special, and worrisome, case of plant succession. A species that is absent, or uncommon, is introduced into a plant community, a small number of individuals establish a foothold, and then, through combinations of allogenic and/or autogenic processes, it becomes a significant (if not dominant) member of the community. For example, some invasive plants release chemicals that inhibit growth in other plants (Russian knapweed), some result in changes in fire regimes (Downy brome or cheatgrass), and some facilitate accumulations of salts near the soil surface (Tamarisk). The natural processes that allow exotic, invasive plants to become dominant members of vegetation communities, that is, the processes of succession, are relatively few and may be exploited by land managers to modify and direct succession into either desirable or undesirable directions.

Plant succession is a function of three controlling mechanisms: species availability, species performance, and resource availability (Fig. A-3). These three controls, the processes that contribute to them, and the factors that modify the processes, are summarized in Figure F-3 and are described in greater detail below.

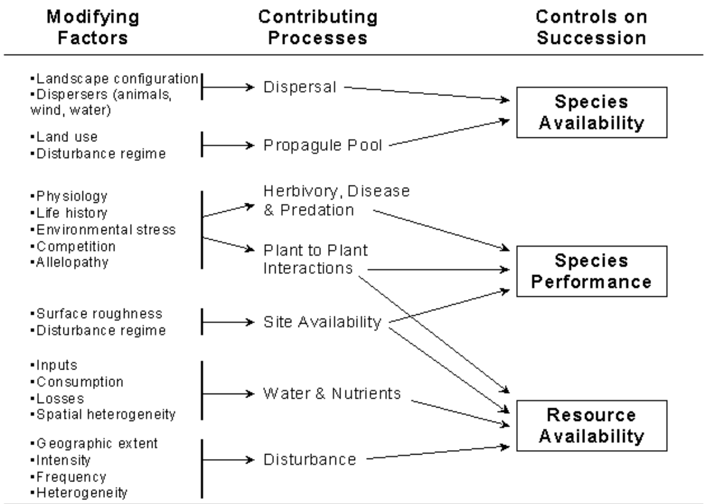

Figure A-3. Diagrammatic representation of the controls on succession, the contributing processes, and modifying factors that can shift processes to favor exotic plant invasions (adapted from Pickett et al. 1987 and Whisenant 1999).

Species Availability

Species availability is one of the three controls on succession (Fig. A-3). If an exotic plant species is not present within the region it cannot become established in a local community. However, an exotic species does not have to be established nearby in order to be of concern. Some plant species can move large distances quite rapidly, especially if dispersal is aided by humans or other animals. For instance, even if the species is nearby, there are processes that may increase or decrease the likelihood that it will disperse into the community of concern to the manager. These processes include dispersal and the dynamics of the propagule pool (Fig. A-3).

Dispersal encompasses the rates and distances and mechanisms that plants use to ensure that some seeds find suitable growing sites. Having some information about the speed and distances that species can disperse will assist managers in knowing what new exotics to be on the lookout for and whether or not particular sites are vulnerable to invasion. Mechanisms include wind and water dispersal of seeds as well as animal dispersal. For example, plants with seeds that can cling to clothing or fur have greater potential to disperse greater distances than those that require going through the digestive track of an uncommon mouse. If a disperser is not available (i.e., that mouse species is absent) then dispersal will not take place, unless a substitute dispersal process is available. Landscape connections or barriers will also modify dispersal. A large expanse of desert may inhibit a wind-dispersed species from arriving at a new site that is otherwise suitable for its growth. A river or large expanse of bare rock may prevent the migration of an animal disperser, and likewise prevent the dispersal of the plant.

A *propagule* is any part of a plant that can regenerate an adult plant. Typically, this means seeds. However, many plants can regenerate from parts of stems (prickly pear cactus and tamarisk) and roots (Russian knapweed). This is a process similar to the propagation of house plants from cuttings. The *propagule pool* is important to consider in succession because it may differ from the vegetation that you see at the time, and may be damaged by disturbance. For instance, it frequently happens that seeds disperse into an area, but conditions are not right for it to germinate. A short-lived seed will die. However, if the seed is long-lived, it may stay in the soil, and germinate one or more years from when it was initially dispersed. In the case of cheatgrass, seeds are produced multiple times per year, and a large number of seeds are stored in the soil (the seed bank). They can germinate under many different conditions. Thus, even if you mow a field after early spring, there are many seeds still present in the soil which can germinate. Even if you use controlled burning to destroy plants, the seed bank is still there.

Species Performance

How well a species performs (grows, competes with other plants, reproduces, etc) in a new site is the second control on succession in Fig. A-3. Even if an exotic species is introduced into a new community, it might not become established and increase in abundance. Whether the exotic plant becomes a member of the community depends on how the new species responds to the numerous processes that can influence its performance. The existence, within the new area of herbivores, diseases, seed predators, other plant species that compete for the same resources, and suitable growing sites all contribute to the success of the exotic.

Site availability is a crucial consideration; if there are no suitable sites for a seed to germinate and an adult plant to grow, then none of the other factors and processes will have an opportunity to act. For instance, soil surface roughness will influence whether or not there are cracks or low spots for a seed to settle. These types of sites are also more likely to accumulate nutrients and water that will promote seed germination. If a site is repeatedly subjected to physical disturbance, say every year, then perennial plants may never become established and the site will be dominated by annuals. The rate at which new sites become available is the one process over which the land manager has the most control. Best management practices that minimize vegetation removal and promote soil stabilization and revegetation efforts will help to minimize the area available for exotic plants to gain a foothold.

Interactions with the existing flora and fauna are also important contributing processes. The presence of *herbivores*, *diseases* and strongly *competitive plants* may reduce performance levels. Being able to escape these processes can greatly contribute to an exotic plant's ability to become established. For example, an exotic plant's physiology may allow it to grow, mature, and set seed during the winter months in the desert. If insect herbivores or disease organisms are active only during the spring and summer, then such an introduced plant may be able to increase more rapidly than an exotic plant whose growth period overlaps that of disease organisms. Additionally, some plant species produce chemicals that make them distasteful to herbivores, or secrete chemicals that inhibit growth of potential competitors (allelopathy). Such a species will have an advantage and is more likely to become an established part of the vegetation community more quickly than a plant that is vulnerable to herbivory or is a weak competitor for important resources. This is one of the reasons invasives do so well in their new environments - natural herbivores, diseases and competitors that keep populations in check in the native habitat are often not transferred with the plant.

Resource Availability

Whether or not important resources (nutrients, water, space) are available, is the third and final control on succession in Fig. A-3. If resources are being efficiently consumed and cycled through an ecosystem, it decreases the likelihood that an exotic plant will be able to invade such a system. When resource availability increases, and the established vegetation community is not able to fully use these new resources, then these resources are available for an exotic plant to exploit.

Most native plant species in arid and semiarid regions have low requirements for *water and nutrients*. Even a slight increase in these resources may result in an excess in the community. Such an increase could come about because plants are consuming less (perhaps because they've been removed) or because resources are being supplied at a greater rate (for example, due to increased precipitation, nitrogen-based pollution, erosion from an upslope site that was disturbed, etc).

Site availability, or space, is also an important resource. Although there appear to be many spaces between plants in arid environments, it is often the case that the roots of these plants overlap, and thus there really are not adequate sites for a new plant to become established. Plant removal, whether by road construction, ditch maintenance, or social trails all increase site availability and thus facilitate invasions by exotic plants.

Disturbance is, of course, a natural part of all vegetation communities. For example, tree falls, floods, rockslides, fires, gopher mounds, and bison wallows are all important processes that allow young plants an opportunity to become established. Different sizes of disturbances tend to happen naturally at predictable time scales. For instance, a large disturbance, such as a forest fire that covers many acres may only affect communities once every 100 to 300 years, while the death of an individual tree may occur every year within a 10 ha plot. Changes in these natural disturbance patterns can result in changes in the vegetation community. For instance, a decrease in the frequency and intensity of flooding allows plants such as tamarisk to colonize sandbars in rivers. Long, continuous clearings of vegetation (such as happens with road maintenance) become conduits for exotic plants to become established throughout a park.

Conclusion

Disturbance and succession are a natural part of community processes. However, when the disturbance regime is changed, opening new resources for plants, invasions can occur, leading to drastic changes in successional processes. However, following BMPs may allow managers to control some of the processes that contribute to exotic plant invasions. Being aware of plants that are poised to move into an area, as well as some of their basic requirements for germination and growth, can help to make invasive control preemptive rather than a series of dealing with large-scale problems.

III. Increasing Invasive Exotic Plant Awareness

Increasing visitor and personnel awareness of the threats and consequences of exotic plant invasions is an important step in protecting wild land ecosystems from these threats. For example, efforts at increasing visitor and personnel awareness of the existence, appearance, function and importance of biological soil crusts have paid off in reduced damage to these fragile organisms. Efforts at increasing awareness of the problems associated with exotic plants can be considered an investment that will be paid of in reduced costs later. The effort required to remove exotic plants and restore invaded ecosystems is many times the effort of preventing the problem initially (refer to Fig. A-2 in Section I). Below are some suggestions; adapting from the "Don't Bust the Crust" program would be a good guide for parks and monuments within the Northern Colorado Plateau Network. Other awareness programs, such as the Air Quality Public Awareness Program at the Black Canyon of the Gunnison River NP will also offer good guidelines.

One objective of a Public Awareness Program is to assist visitors and personnel in identifying and increasing their awareness of exotic plant species that are threatening to invade lands under management.

- Awareness efforts can include the following approaches (see below for more detailed recommendations and see Section V for links with more suggestions):
    - Brochures & pamphlets
    - Signs
    - Interpretive posters
    - Weed & seed disposal containers at trailheads & visitor centers
    - Tours for visitors and volunteers
    - On-site photo exhibits of before & after weed removal efforts

A second objective is to avoid moving weed seeds or propagules into the backcountry, and to prevent new weed infestations and the spread of existing weeds and to avoid or remove sources of weed seed and propagules, awareness programs should include instructions and advice for the following actions that can be taken by visitors and personnel.

- Inspect and clean clothing, boots, packs, tents, bikes, and other equipment before taking going into a new area. Remove all seeds and plant material. Deposit in garbage cans.
- Ask about what the problem weeds look like and where they are problems.
- Do not leave campgrounds except via constructed trails and roads.
- Volunteer to help with trailhead exotic plant removal efforts.
- Inspect and clean motorized and mechanized trail vehicles of weeds and their seeds.
- Keep dogs and other pets free of weed seeds, especially if pets are allowed at campgrounds.
- Avoid picking unidentified "wildflowers" and discarding them along trails or roadways.
- Avoid dumping aquarium water or aquatic plants into local waters. Many plants for water gardens and aquaria are highly invasive.
- Support the development and distribution of weed-free or weed-seed-free feed, hay, straw, and mulch.
- Brochures and posters should describe efforts at exotic plant removals and the annual costs for these efforts (to be compared to the costs for prevention).

<u>BMPs that Serve to Increase Invasive Exotic Plant Awareness</u>

Objective: Identify and increase awareness of exotic plant species that are threatening to invade lands under management.

- Contact appropriate personnel in state and county weed agencies on a regular basis to keep informed on the latest threats in the area and to update these guidelines with the current Best Practices for prevention.

- ❑ Communicate regularly with neighboring landowners and agencies to stay apprised of invasive threats and to coordinate prevention activities.

Objective: Improve effectiveness of prevention practices through weed awareness and education.

- ❑ Educate personnel and visitors in weed identification, biology, impacts, and effective prevention measures.
- ❑ Provide proficient weed management expertise at each administrative unit of a public land management agency. Expertise means that necessary skills are available and corporate knowledge is maintained.
- ❑ Develop or adopt weed-awareness programs or literature for local residents, fishing and hunting license-holders, outfitters, backcountry campers and other visitors.
- ❑ Develop incentive programs for personnel and visitors encouraging weed awareness, detection, reporting, and identifying new invaders.

Objective: Set an example by maintaining weed-free administrative sites.

- ❑ Treat weeds at administrative sites and visitor centers and use weed prevention practices to maintain sites in a weed-free condition.
- ❑ Post "before & after" pictures of exotic plant removal efforts to increase awareness of native vs. invaded vegetation looks like and awareness of the effort it takes to maintain natural ecosystems.

<u>*Working with Terrestrial Recreationists and Wilderness Users*</u>

Objective: Avoid moving weed seeds or propagules into the backcountry, and to prevent new weed infestations and the spread of existing weeds and to avoid or remove sources of weed seed and propagules.

- ❑ Maintain trailheads, campgrounds, visitor centers, boat launches, picnic areas, roads leading to trailheads, and other areas of concentrated public use in a weed-free condition. Consider high-use recreation areas as high priorities for weed eradication.
- ❑ Develop a list of simple prevention practices to provide to backcountry campers and fishing license-holders. This should include mention of the important role of robust, undisturbed native vegetation and biotic soil crusts in deterring weed invasions and in facilitating repair and restoration of vegetation.
- ❑ Develop a guide to assist visitors in self-inspection of vehicles and equipment at park entrance areas. Include a "most wanted" list with sketches or photos of propagules.
- ❑ Provide containers at parking lots, campgrounds, trailheads, and river access points for visitors to deposit removed seeds.
- ❑ Sign trailheads and access points that are not scheduled for treatment to assist in educating visitors on the consequences of their activities.
- ❑ In areas susceptible to weed infestation, limit vehicles to designated, maintained travel routes. Inspect and document travel corridors for weeds and treat as necessary.

Aquatic Area Management, Recreation, and Outfitting

Objectives: Prevent new weed infestations and the spread of existing weeds; avoid or remove sources of seeds and propagules; and, avoid moving weeds between bodies of water.

- ❑ Promptly post signs if aquatic invasives are found. Confine infestation; where prevention is infeasible or ineffective, close facility until infestation is contained.

- Inspect, wash and dry boats, personal watercraft, tackle, float tubes, waders, nets, downriggers, anchors, floors of boats, props, axles, trailers, bilges and all wells, bait buckets, and other boating equipment to remove or kill harmful species not visible at boat launch before transporting to new waters. Use hot (40°C / 104°F) clean water or a high-pressure sprayer, or allow boat and equipment to dry for a minimum of five days.
- Divers should clean their equipment after each use. Be especially careful to wash the buoyancy control device and other items that retain water. All gear should be rinsed with water heated to at least 40°C / 104°F and everything should be allowed to dry completely between dives.
- Construct new boat launches and ramps at deep-water sites. Restrict motorized boats in lakes near areas that are infested with weeds. Move sediment to upland or quarantine areas when cleaning around culverts, canals, or irrigation sites. Inspect and clean equipment before moving between project areas.
- Maintain l00-foot weed-free clearance around boat launches and docks.

Working with Outfitters & Contractors

Objective: Avoid moving weed seeds or propagules into the backcountry.

- Develop or adopt weed-awareness programs or literature for local residents, fishing and hunting license-holders, outfitters, backcountry campers and other visitors.
- Develop stipulations that prohibit transportation of weed contaminated forage or feeds through NPS lands.
- Noxious weeds can be introduced in livestock dung. Feed pack and saddle stock only weed-free feed for several days before traveling into the backcountry.
- Inspect, brush, and clean animals (especially hooves and legs) before entering public land. Inspect and clean tack and equipment.
- Regularly inspect trailheads and other staging areas for backcountry travel. Bedding in trailers and hay fed to pack and saddle animals may contain weed seed or propagules.
- Tie or hold stock in ways that minimize soil disturbance and avoid loss of desirable natives.
- Use weed-free feed in the backcountry

Managing Wildlife

Objective: Avoid creating soil conditions that promote weed germination and establishment.

- Periodically inspect and document areas where wildlife concentrate in the winter and spring that might result in overuse or soil scarification.
- Use weed-free materials for all wildlife management activities.

IV. Best Management Practices for Preventing Exotic Plant Invasions

A Best Management Practice (BMP) is a recommended site management and/or maintenance activity, usually based on an approach that has been shown to work effectively for the purpose intended. A BMP is based on the use of readily available equipment and/or technology. Implementation of BMPs will allow the land manager to minimize the negative consequences that can accompany almost any necessary action (for example, road maintenance, fire fighting, and camp ground modifications). Following BMPs can also reduce liability with regard to potential agency or citizen lawsuits, and can be of economic benefit to the practitioners by reducing the likelihood that cumbersome and expensive land remediation efforts will need to be undertaken.

The BMPs that follow have been adopted from those in use by other federal land management agencies, in particular the U.S.D.A. Forest Service and the D.O.I Bureau of Land Management. These practices, when implemented, can effectively reduce invasions by exotic plants on public lands in the western United States. Since each land holding is unique, site-specific solutions are not presented. Rather, land managers, with the assistance of appropriate specialists, should use this guide to identify and select the most appropriate BMPs for the land under their responsibility. BMPs may be modified as necessary in order to best achieve the goal for each type of activity covered in this guide.

<u>Grazing Management</u>

GOAL: Grazing management operations do NOT enhance opportunities for spread of invasive weeds on National Park Service holdings and, where possible, serve to control, limit, or reduce the spread of invasive weeds. *The practices below should be followed unless the intent of the goal can be met with a more effective practice.*

Objective: Incorporate noxious weed prevention and control practices in the management of grazing allotments.

- Consider prevention practices and cooperative management of weeds in grazing allotments. Prevention practices may include (see below for detailed recommendations):
  - Altering season of use
  - Exclusion
  - Weed control methods
  - Revegetation
  - Education
  - Activities to minimize ground disturbance
  - Preventing weed seed transportation
  - Maintaining healthy vegetation
  - Inspection
  - Reporting

Objective: Avoid or remove sources of weed seed and propagules to prevent new weed infestations and the spread of existing weeds, and to minimize transport of weed seed into and within allotments.

- If livestock may contribute to seed spread in a weed-infested area, schedule livestock use for prior to seed-set or after seed has fallen.
- If livestock were transported from a weed-infested area, annually inspect and treat entry units for new weed infestations.
- Close infested pastures to livestock grazing when grazing will either continue to exacerbate the condition or contribute to weed seed spread. Designate those pastures as unsuitable range until weed infestations are controlled.
- Whenever possible, provide supplemental feeding in a designated area so new weed infestations can be detected and treated immediately. Pelletized feed is unlikely to contain viable weed seed.
- Noxious weeds can be introduced through seeds in livestock dung. Keep new livestock (especially livestock that may have been fed poor-quality hay) in a holding field for 24 to 48 hours before releasing onto open range.

Objective: Maintain healthy, desirable vegetation that resists weed establishment.

- Manage the timing, intensity (utilization), duration, and frequency of livestock activities to maintain the competitive ability of desirable plants and retain live plant cover and litter. The objective is to manage such that grazers are prevented from selectively removing desirable plant species and leaving undesirable species.

- Manage livestock grazing on restoration areas to ensure that desired vegetation is well established. This may involve exclusion for a period of time. Consider practices to also minimize wildlife grazing on the areas, if necessary.
- Reduce ground disturbance, including damage to biological soil crusts. Consider changes in the timing, intensity, duration, or frequency of livestock use; location and changes in salt grounds; restoration or protection of watering sites; and restoration of yarding/loafing areas, corrals, and other areas of concentrated livestock use.
- Inspect areas of concentrated livestock use for weed invasion. Especially focus on watering locations and other resource-rich environments that may be particularly susceptible to invasion. Inventory and manage new infestations.
- Use education programs or annual operating instructions to increase weed awareness.

<u>Fire Management</u>

GOAL: Fire program operations do NOT enhance opportunities for spread of invasive weeds on National Park Service holdings and, where possible, serve to control, limit, or reduce the spread of invasive weeds. *The practices below should be followed unless the intent of the goal can be met with a more effective practice.*

<u>Increasing Awareness during Pre-Incidence and Fire Planning Stages</u>

Objective: Improve effectiveness of prevention practices through weed awareness and education.

- Provide training materials and training to seasonal fire staff on invasive wee identification and weed prevention BMPs.
- For prescribed burns, inventory the project area and evaluate potential weed spread with regard to the fire prescription.
- Ensure that a weed specialist is included in a Fire Incident Management Team when wildfire or control operations occur in or near a weed-infested area.
- Include weed risk factors and weed prevention considerations in all wildland fire and prescribed fire management actions.
- Provide weed documentation forms to be included with Initial Attack Incident Commander, the Prescribed Fire Monitor, and the Engine Boss, Resource Advisor, Air Operations Branch Director kits, as appropriate for type of fire incident.
- Resources can include local noxious weed pocket guides, videos such as *Noxious Weeds: A Biological Wildfire* and *Explosion in Slow Motion: Weeds on Western Lands*, and laminated identification cards such as *Leave No Weeds*.

Objective: Avoid or remove sources of weed seed and propagules to prevent spreading weeds.

- Provide dispatch with information on known weed infestation areas - update annually.
- Use operational practices to reduce weed spread (for example, avoid weed infestations when locating fire lines).
- Locate, identify, periodically inspect, and treat weeds in potential runway and helibase areas, staging areas, incident command posts & base camps, practice jump areas, etc.
- When invasive weeds have been identified on an Incident Scene, clean all vehicles that have been in infested site and insect clothing on personnel that have traveled on foot through site.

<u>Fire Management Plans</u>

Objective: Avoid creating post-fire conditions conducive to invasive weeds that come about due to well-intentioned, but mis-timed followup activities.

- Prescribed fire burn plans will include pre-burn invasive weed inventory and risk assessment components, as well as post-burn mitigation components.
- Integrate prescribed fire and other weed management techniques to achieve best results. This may involve post-burn herbicide treatment or other practices that require careful timing.
- Include weed prevention and follow-up monitoring in all prescribed fire activities. Include in burn plans, the possibility that post-burn weed treatment may be necessary.
- Implementation Plans for Wildland Fire for Resource Benefit will include considerations and mitigation measures for control of weed establishment and spread.

Fire Operations

Objective: Avoid or remove sources of weed seed and propagules to prevent new weed infestations and the spread of existing weeds.

- Ensure that rental and interagency equipment is free of weed seed and propagules during check-in or otherwise prior to assignment. [Also, inspect and clean all owned vehicles that have traveled off-site prior to allowing them to return home.]
- Inspect and treat weeds that establish at equipment cleaning sites after fires.
- Establish incident bases, staging areas, and landing zones in areas that are verified to be free of invasive weeds.
- If placement of operations facilities in weed-infested areas cannot be avoided, mow areas of concentrated activity if weeds are not yet setting seed. If weeds are setting seeds, designate travel routes on weed-free paths.
- Cover weed infested cargo areas and net-loading areas with tarps if weeds are on site and can't be removed or avoided.
- Flag off high-risk weed infestations in areas of concentrated activity and show weeds on facility maps.
- Establish power wash stations at or near incident bases and helibases if fire operations involve travel or work in weed infested areas. Wash all vehicles and upon arrival from and prior to departure to each incident, including fuel trucks and other service vehicles.

Objective: Avoid creating soil conditions that promote weed germination and establishment.

- Use fire suppression tactics that reduce disturbances to soil and vegetation.
- Avoid moving water buckets from aquatic-weed-infested lakes to lakes that are not infested. There is no hazard in using water infested with aquatic weeds on terrestrial sites.
- Avoid ignition and burning in areas at high risk for weed establishment or spread. Treat weeds that establish or spread.

Fire Rehabilitation

Objective: Prevent conditions favoring weed establishment and to re-establish vegetation on disturbed ground as soon as possible.

- To prevent weed spread, treat weeds in burned areas. The first preference is prevention..

- Determine soon after a fire whether revegetation is necessary to speed recovery of a competitive plant community, or whether desirable plants in the burned area will recover naturally. Consider the severity of the burn and the proportion of weeds to desirable plants on the land before it burned. In general, more severe burns and higher pre-burn weed populations increase the necessity of revegetation. Consider revegetating an area if the desired plant cover is only 20 to 30%. Apply for funding during the Incident.
- Replace soil and vegetation "green side up" when rehabilitating fire lines.
- Inspect, document, and monitor weed establishment at fire access roads, cleaning sites, all disturbed staging areas, and within burned areas. Control infestations to prevent spread within burned areas.
- Schedule recon approximately one year post-fire to identify weed infestations that may be moving into burned areas.
- Seed and straw mulch to be used for burn rehabilitation (for wattles, straw bales, dams, etc.) should be inspected and certified that they are free of weed seed and propagules.
- Regulate human, pack animal, and livestock entry into burned areas until desirable vegetation has recovered sufficiently to resist weed invasion.
- Develop a burned-area integrated weed management plan, including a monitoring component to detect and eradicate new weeds early.

Maintenance, Construction, and Road Repair

GOAL: Maintenance, construction, and road repair operations do NOT enhance opportunities for spread of invasive weeds on National Park Service holdings and, where possible, serve to control, limit, or reduce the spread of invasive weeds. *The practices below should be followed unless the intent of the goal can be met with a more effective practice.*

Site-Disturbing Projects and Maintenance Programs

Objectives: Incorporate weed prevention and control into project layout, design, and evaluation, as well as all project decisions and to build and maintain healthy plant communities that will effectively compete with weeds.

- Environmental analyses for projects and maintenance programs should assess weed risks, analyze high-risk sites for potential weed establishment and spread, and identify prevention practices. Determine weed prevention and management needs at the onset of project planning.
- Include site-specific vegetation monitoring objectives in project plans. Recognize desirable plants as well as weeds.

Objective: Avoid or remove sources of weed seed and propagules to prevent new weed infestations and the spread of existing weeds.

- Before ground-disturbing activities begin, inventory and prioritize weed infestations for treatment in project operating areas and along access routes. Identify what weeds are on site or within the vicinity and do a risk assessment accordingly. Control weeds as necessary.
- Begin project operations in non-infested areas. Restrict movement of equipment and machinery *from* weed-contaminated areas *to* non-contaminated areas. This includes machinery used for or by construction, recreation, agriculture, forestry, oil and gas exploration and production, utility companies, mining, and tourism.

- Locate and use weed-free project staging areas. Avoid or minimize travel through weed-infested areas, or restrict travel to periods when spread of seed or propagules is least likely.
- Identify sites where equipment can be cleaned. Remove mud, dirt, and plant parts from project equipment before moving it into a project area. Seeds and plant parts should be collected and incinerated when practical.
- Clean all equipment before leaving the project site if operating in weed infested areas.
- Inspect, remove, and properly dispose of weed seed and plant parts found on clothing and equipment. Proper disposal means bagging and incinerating seeds and plant parts.
- Coordinate project activities with nearby herbicide applications to maximize cost effectiveness of weed treatments.
- Evaluate options to regulate the flow of traffic on sites where desired vegetation needs to be established or maintained.

Objectives: Prevent the introduction and spread of weeds caused by moving infested sand, gravel, and fill material and to work with and encourage the responsible transportation agencies to voluntarily adopt these practices.

- Inspect materials on origination site to ensure that they are weed-free before transport and use. If sources of sand, gravel, and fill are infested, eradicate weeds, then strip and stockpile the contaminated material for several years, if possible, checking regularly for weed re-emergence.
- When material from a weed-infested but treated source is used in a project, inspect and document the project area annually for at least three years to ensure that any weeds transported to the site are promptly detected and controlled.
- Maintain stockpiled, non-infested material in a weed-free condition.

Objective: Avoid creating environmental conditions that promote weed germination and establishment.

- Minimize soil disturbance.
- If a disturbed area must be left bare for a considerable length of time, cover the area with plastic until revegetation is possible.
- When working in vegetation types with relatively closed canopies, retain shade to the extent possible to suppress weeds and prevent establishment and growth.
- Retain native vegetation in and around project activity as much as possible.

Objective: Re-establish vegetation to prevent conditions conducive to establishment of weeds when project disturbances create bare ground.

- Revegetate disturbed soil to optimize plant establishment for that specific site. Define for each project what constitutes disturbed soil and objectives for revegetation.
- Revegetation may include topsoil replacement, planting, seeding, fertilization, liming, and weed-free mulching as necessary. Use native material where appropriate and feasible. Consider hiring a contractor to chip local brush or cut and bale local weed-free grass for mulch - an added benefit is that seeds in the grass or brush can help restore localized vegetation on the site. Use certified weed-free or weed-seed-free hay or straw where certified materials are required or available.

- Monitor sites where seed, hay, straw, or mulch has been applied. Eradicate weeds before they seed. In contracted projects, contract specifications can require that the contractor maintain the site weed-free for a specified time.
- Where practical, stockpile weed-seed-free topsoil and replace it on disturbed areas (for example, road embankments or landings).
- Use local seeding guidelines to determine procedures and appropriate seed mixes. A certified seed laboratory needs to test each lot according to Association of Seed Technologists and Analysts (AOSTA) standards (which include an all-state noxious weed list) and provide documentation of the seed inspection test. Check state and federal lists to see if any local weeds need to be added prior to testing. Non-certified seed should be tested before use.
- Inspect and document all ground-disturbing operations in noxious weed infested areas for at least three growing seasons following completion of the project. For ongoing projects, continue to monitor until reasonably certain that no weeds have appeared. Plan for follow-up treatments based on inspection results.

Objective: Incorporate weed prevention into road and utility project layout, design, evaluation, and decisions.

- Remove mud, dirt, and plant parts from project equipment before moving it into a project area. Seeds and plant parts should be collected and incinerated when practical.
- Clean all equipment before leaving the project site if operating in areas infested with weeds. Seeds and plant parts should be collected and incinerated when practical.
- Communicate with the local weed district or weed management area about projects and best practices for prevention.
- To avoid weed infestation, build and maintain healthy plant communities whenever possible, including utility rights of way, roadsides, highway landscaping projects, rest area construction, scenic overlooks, and entrances.

Objective: Minimize roadside sources of weed seed that could be transported to other areas.

- Periodically inspect roads and rights-of-way for noxious weeds. Train road maintenance staff and utility truck operators to recognize weeds and report locations to the local weed specialist. Inventory weed infestations and schedule them for treatment.
- Restrict transportation of non-certified weed-free forage and hay on through roads.
- Schedule and coordinate blading or pulling of noxious weed-infested roadsides or ditches in consultation with the local weed specialist. Do not blade or pull roadsides and ditches infested with noxious weeds unless doing so is required for public safety or protection of the roadway. If the ditch must be pulled, ensure weeds remain on-site. Blade from least infested to most infested areas. When it is necessary to blade noxious weed-infested roadsides or ditches, schedule activity when seeds or propagules are least likely to be viable and spread.
- Avoid acquiring water for road dust abatement where access to water is through weed-infested sites.
- Treat weeds in road decommissioning and reclamation projects before roads are made impassable. Re-inspect and follow up based on initial inspection and documentation.

V. Additional Materials and Further Information

Selected Relevant Literature:

Hobbs, R.J. and S.E. Humphries. 1995. An integrated approach to the ecology and management of plant invasions. *Conservation Biology* 9:761-770.

Luken, J.O. and J.W. Thieret, editors. 1997. *Assessment and Management of Plant Invasions*. Springer-Verlag, New York, NY. 324pp.

Pickett, S.T.A., S.L. Collins and J.J. Armesto. 1987. Models, Mechanisms and Pathways of Succession. *The Botanical Review* 53:335-371.

Whisenant, S.G. 1999. *Repairing Damaged Wildlands: A Process-Oriented, Landscape-Scale Approach*. Cambridge University Press, Cambridge, UK. 312pp.

White, P.S. and S.T.A. Pickett. 1985. Natural disturbance and patch dynamics: an introduction. Pages 3-13 in S.T.A. Pickett and P.S. White (eds). *The Ecology of Natural Disturbance and Patch Dynamics*. Academic Press, San Diego.

Whitford, W.G. 2002. *Ecology of Desert Systems*. Academic Press, San Diego. 343 pp.

Links to weed sites: (and general plant and management sites with good weed information)

Title	Link
Databases	
Global Invasive Species Database	http://www.issg.org/database/welcome/
The PLANTS Database	http://plants.usda.gov/index.html
Invaders Database System	http://invader.dbs.umt.edu/
Integrated Taxonomic Information System	http://www.itis.usda.gov/
Information: Gov. Sites	
BLM's Weed Website	http://www.blm.gov/weeds/
Information: Non-Gov. Sites	
TNC Wildland Invasive Species Program page	http://tncweeds.ucdavis.edu/
Exotic Plants Bibliography	http://www.npwrc.usgs.gov/nextbuild/resource/literatr/exotic/exotic.htm
Invasive Species Node Home Page (NBII)	http://www.nrel.colostate.edu/projects/nbii/nbii.html

Title	Link
Invasive Species: The Nation's Invasive Species Information System	http://www.invasivespecies.gov/index.shtml
Invasive Species: National Invasive Species Management Plan	http://www.invasivespecies.gov/council/nmp.shtml#html
Plant Conservation Alliance - Alien Plant Working Group	http://www.nps.gov/plants/alien/
Southwest Exotic Plant Information Clearinghouse	http://www.usgs.nau.edu/SWEPIC/index.html
Preserving Our Natural Heritage - A Strategic Plan for Managing Invasive Nonnative Plants on National Park System Lands	http://www1.nature.nps.gov/wv/strat_pl.htm
NBII - ISIN	http://invasivespecies.nbii.gov/index.html
Invasive Weeds	http://www.invasiveweeds.org/
NAWMA	http://www.nawma.org/

NPS Alien Plant Working Group - Info Links	http://www.nps.gov/plants/alien/moreinfo.htm
Nonindigenous Aquatic Species	http://nas.er.usgs.gov/fishes/fishes.htm
Noxious Times Noxious Invasive Weed Newsletter	http://pi.cdfa.ca.gov/noxioustimes/
Noxious Weeds: A Biological Wildfire	http://extension.usu.edu/publica/agpubs/wildfire.pdf
Exotic and Invasive Species on the Colorado Plateau	http://www.cpluhna.nau.edu/Biota/invasive_exotics.htm
Invasive Species: Manager's Tool Kit	http://www.invasivespecies.gov/toolkit/main.shtml
Weeds Website	http://www-a.blm.gov/weeds/
States: UTAH	
BLM Utah Weed Program	http://www.blm.gov/utah/resources/weeds/
THE WEED WEB	http://extension.usu.edu/weedweb/index.htm
BLM-Bureau of Land Management-Utah-Healthy Productive Lands-Noxious Weeds	http://www.ut.blm.gov/wh3noxweeds.html
Moab Field Office	http://www.ut.blm.gov/moab/index.html
BLM Utah, Moab Field Office Home Page	http://www.blm.gov/utah/moab/index.html
States: Colorado	
Colorado Weed Management Association	http://www.cwma.org/
Weed Watch (CWMA Newsletter)	http://www.cwma.org/5_news.html
Colorado Department of Agriculture	http://www.ag.state.co.us/
Noxious Weed Program	http://www.ag.state.co.us/dpi/weeds/weed.html
BLM Colorado - Weed Management Home Page	http://www.co.blm.gov/botany/weedhome.htm
States: OTHER	
California Exotic Pest Plant Council	http://www.caleppc.org/
Miscellaneous Sites	
THE ECOLOGY OF INVASIVE SPECIES	http://culter.colorado.edu:1030/~tims/class00.html
Invasive Plants & Animals in Iowa: A Symposium	http://www.ag.iastate.edu/departments/aecl/invasives/
Center for Invasive Plant Management	http://www.weedcenter.org/
Cooperative Extension Catalog of Publications--Weeds	http://www.ianr.unl.edu/pubs/Weeds/index.htm

Title	Link
Colorado State Cooperative Extension Natural Resources Publications	http://www.ext.colostate.edu/PUBS/NATRES/pubnatr.html

Other Best Management Principles Guidelines:

Title	Link	Comments
Guides		
Ecological Invasive Plant Management Textbook	http://www.weedcenter.org/textbook/index.html	Center for Invasive Plant Management
Integrated Weed Management Guidelines	http://www.blm.gov/education/weed/paws/IWM21.html	Colorado Integrated Weed Management Plant, Partners Against Weeds (PAWs)
Noxious Weed Management Amendment	http://www.co.blm.gov/botany/lolostip.htm	USFS Lolo National Forest Plan
Guidelines for Coordinated Management of Noxious Weeds	http://www.weedcenter.org/management/management.html	Center for Invasive Plant Management

Sample brochures (templates, activities), etc.:

Title	Link	Comments
Brochures		
Tours		
California Weed Awareness Week	http://groups.ucanr.org/ceppc/Organizing_a_weed_tour/	CalEPPC

Guidelines and Standards for Weed Management Areas:

Title	Link	Comments
Guidelines for Coordinated Management of Noxious Weeds: Development of Weed Management Areas	http://www.weedcenter.org/management/guidelines/tableofcontents.html	Center for Invasive Plant Management [Includes sample contracts, agreements and memoranda of understanding]
Guidelines for Prioritizing Weed Management	http://tncweeds.ucdavis.edu/products/www-wb/wwwbapp4.rtf	An appendix from a TNC guide
Guidelines for Noxious Weed Management Plans	http://www.co.weld.co.us/departments/weed_pest/pdf/Guide4WeedManPlan.pdf	For Weld Cty, Colorado

APPENDIX B. OVERVIEW OF THE NEED FOR ECOLOGICAL ASSESSMENTS TO SUPPORT THE DESIGN AND IMPLEMENTATION OF VITAL-SIGNS MONITORING

To provide early warning of adverse ecological changes (an important goal of NPS vital-signs monitoring -- http://science.nature.nps.gov/im/monitor/), sampling designs should be developed so that monitoring is conducted where and when the probabilities (or *risks*) of rapid and/or irreversible ecological changes are greatest. Sampling designs that are strategically stratified on the basis of *risk* can be developed on the basis of *ecological assessments*. Ecological assessments use multiple sets of biophysical data to evaluate the relative social and ecological value of ecosystems, the existing status or condition of ecosystems (defined on the basis of vital signs such as soil stability, hydrologic function, biotic integrity, and disturbance regime) *and* the risk of that status changing to a less healthy state (Whitford 1998). Condition (or "health") is described or quantified in relation to benchmark conditions identified at extant reference areas or in studies documenting the historic range of variability. Information provided by ecological assessments is synthesized and used to inform the development of a monitoring design which cost-effectively maximizes the ability of the monitoring program to support pro-active, pre-emptive resource-management decisions.

Three sets of questions are central to the concept of ecological assessments:

1. *What ecosystems or ecosystem properties are inherently most resistant and resilient in relation to predominant natural disturbances and anthropogenic stressors?* For example, rocky soils are inherently more resistant to trampling or OHV impacts than sandy soils. Likewise, stream reaches characterized by bedrock constraints or bouldery bed and bank materials are inherently more resistant to trampling or OHV impacts than alluvial reaches. Because of greater resource availability, riparian ecosystems are inherently more resilient to most anthropogenic impacts than arid upland ecosystems.

2. *What is the existing condition of ecosystems in terms of structure / composition and the functioning of key ecological processes? Have anthropogenic changes in ecosystem condition affected ecosystem resistance and resilience to predominant natural disturbances and anthropogenic stressors?* For example, rangeland ecosystems impacted by past or current grazing practices may be less resistant and resilient to impacts of drought and may be more susceptible to invasion by exotic species. Ponderosa pine ecosystems impacted by decades of fire suppression are likely to be more susceptible to catastrophic crown fire. Riparian ecosystems impacted by OHV activities may be more susceptible to channel incision following flood events.

3. *What are the predominant anthropogenic factors that threaten park ecosystems, and how does threat severity vary spatially across landscapes and through time?* For example, where backcountry visitation is a primary anthropogenic factor affecting park ecosystems, it is important for the monitoring program to know where backcountry trails and campsites occur in relation to those ecosystems or ecosystem components (e.g., soils) which are least resistant / resilient to visitation impacts.

Several types of information are required to support ecological assessments and the development of strategically stratified sampling designs:

Upland ecosystems

1. *Soil maps* – Soil maps provide information that is essential for assessments of ecosystem susceptibility to anthropogenic impacts. Soil and ecosystem resistance / resilience to particular human impacts vary according to texture, depth, chemical composition, landscape position, and extent / type of biological soil crust cover. Ecological site descriptions that are linked to soil maps provide a fundamental source of information concerning the structure / composition and dynamics of benchmark ecosystems. For purposes of monitoring design, soil information must be digital and of sufficient spatial resolution to match management needs. (Required to support questions 1 and 2 above.)

2. *Condition assessments* – Condition assessments provide essential information concerning the current status of ecosystems and how ecosystem resistance / resilience has been impacted by anthropogenic factors and natural disturbances. For rangeland ecosystems, existing protocols are available for assessing soil / site stability, hydrologic functioning, and biotic integrity (Pellant et al. 2000, Pyke et al. 2002). Protocols also are available for assessing the condition of fire regimes, and such assessments are required components of NPS fire-management plans. (Required to support question 2 above.)

Riverine ecosystems

1. *Stream-type classificiations* – Analogous to soil maps for upland ecosystems, stream classifications categorize stream reaches on the basis of gradient, bed and bank material, and channel morphology (e.g., Rosgen 1994, 1996). These are key parameters affecting the resistance / resilience of riverine ecosystems to natural disturbances and anthropogenic stressors. (Required to support questions 1 and 2 above.)

2. *Condition assessments* – As described for upland systems, condition assessments provide essential information concerning the current status of ecosystems and how ecosystem resistance / resilience has been impacted by anthropogenic factors and natural disturbances. Existing protocols are available for assessing the hydrologic functioning and biotic integrity of riparian ecosystems (Prichard et al. 1998). (Required to support question 2 above.)

Spring – seep ecosystems

As for upland and riverine ecosystems, ecological assessments of spring-seep ecosystems (including hanging gardens) require a classification scheme and on-the-ground condition assessments. Protocols for spring-seep systems are less well-developed than for upland and riverine systems.

Literature Cited

Pellant, M., P. L. Shaver, D. A. Pyke, and J. E. Herrick. 2000. *Interpreting indicators of rangeland health. Version 3. Interagency technical reference TR-1734-6*. U.S. Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO.

Prichard, D., J. Anderson, C. Correll, J. Fogg, K. Gebhardt, R. Krapf, S. Leonard, B. Mitchell, and J. Staats. 1998. *Riparian area management : A user guide to assessing proper functioning* *condition and the supporting science for lotic areas. Interagency technical reference 1737-15*. U.S. Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO.

Pyke, D. A., J. E. Herrick, P. L. Shaver, and M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. *Journal of Range Management* 55: 584-597.

Rosgen, D. L. 1994. A classification of natural rivers. *Catena* 22: 169-199.

Rosgen, D. L. 1996. *Applied river morphology*. Wildland Hydrology, Pagosa Springs, CO.

Whitford, W. G. 1998. Validation of indicators. Pages 205-209 in D. J. Rapport, R. Costanza, P. R. Epstein, C. Gaudet, and R. Levins, eds. *Ecosystem health*. Blackwell Science, Malden, MA.